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Calgary, Alberta
August 27 - 31, 1989
Volume I

Heritage Fund

Alberta
LAND CONSERVATION AND
RECLAMATION COUNCIL
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Technical Advisory Committee

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Regulating surface disturbances in Alberta is the responsibility of the Land Conservation and Reclamation Council. The Council executive consists of a Chairman from Alberta Environment and two deputy chairmen from Alberta Forestry, Lands and Wildlife. The Council oversees a reclamation research program, established in 1978, to identify the most efficient methods for achieving acceptable reclamation in the province. Funding for the research program is provided by Alberta's Heritage Savings Trust Fund, Land Reclamation Program.

To assist with development and administration of the research program, the Council appointed the interdepartmental Reclamation Research Technical Advisory Committee (RRTAC). The Committee consists of eight members representing the Alberta Departments of Agriculture, Energy, Forestry, Lands and Wildlife, and Environment, and the Alberta Research Council. The Committee updates research priorities, reviews research proposals, organizes workshops, and otherwise acts as the coordinating body for reclamation research in Alberta.

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Proceedings of the Conference

Reclamation, A Global Perspective

held in Calgary, Alberta, Canada

August 27-31, 1989

Organized by the

Canadian Land Reclamation Association/
Association Canadienne de Réhabilitation des Sites Degradés

and the

American Society for Surface Mining and Reclamation

Compiled by

D.G. Walker, C.B. Powter, and M.W. Pole

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Disclaimer

The papers contained in this proceedings were peer-reviewed and comments provided to the authors. However, it was the final responsibility of the authors to address these comments.

The content, recommendations and conclusions in this report are therefore those of the authors and not of the Alberta Government or its representatives.

This report is intended to provide govenment and industry staff with up-to-date technical information to assist in the preparation and review of Development and Reclamation Approvals, and development of guidelines and operating procedures. This report is also available to the public so that interested individuals similarly have access to the most current information on land reclamation topics.

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This conference was jointly organized by the Canadian Land Reclamation Association/Association Canadienne de Réhabilitation des Sites Degradés and the American Society for Surface Mining and Reclamation. The following members of these organizations were particularly helpful: Stu Bengson, Richard Barth, Daniel Boivin, Jon Burley, Kent Crofts, Al Fedkenheuer, Gail Harrison, Darlene Hergott, Al Kennedy, Tom Oddie, Les Panek, Bill Plass, Mike Pole, Chris Powter, Holly Quan, Ron Ries and David Walker. Mr. Marc St.-Onges provided the French translations for the Abstracts. The success of the conference was also due to the efforts of several people who helped out on the registration desk and with the audio/visual systems.

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A special note of thanks to the Reclamation Research Technical Advisory Committee of the Alberta Land Conservation and Reclamation Council for publishing these proceedings.

Finally, but perhaps most importantly, the following page lists the organizations that sponsored the conference, either in the form of a direct financial contribution, or through the donation of time, supplies or services for the organizers to complete their tasks. The support of these organizations is greatly appreciated.

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Reclamation, A Global Perspective

Session Chairman: C.B. Powter

INTEGRATED SOIL AND WATER IMPROVEMENT PROJECT, EGYPT: SOIL IMPROVEMENT PROGRAM*

by

L.A. Leskiw**

Abstract. The Canadian International Development Agency in co-operation with the Government of Egypt is conducting a five-year multi-million dollar land improvement project on 30,000 ha on the Nile Delta. Soils throughout most of the project area, and in a substantial portion of the Nile Delta, have high water tables and extensive salinity and sodicity problems; hence, the need for land reclamation on a large scale. To improve the soils this project is employing an integrated approach consisting of several key components: basic data collection, irrigation system improvements, drainage improvement, soil improvement, extension services, social development, training, and project management. This presentation concentrates on the soils and agricultural conditions and planned reclamation activities, emphasizing the need for integration among project components.

Additional Key Words: Nile Delta, Agricultural development.

Introduction

The Integrated Soil and Water Improvement Project (ISAWIP) is a major undertaking to improve agricultural lands and increase agricultural productivity in three Markaz (Dikirnis, Minyet El Nasr and El Manzala) of the Daqahliya Governorate in Egypt.

The Canadian International Development Agency and the Government of Egypt are jointly financing the planning and the implementation of the project. The Ministry of Irrigation, the Ministry of Agriculture and the Governorate of Daqahliya will share the responsibilities for the planning and implementation of the project. For an excellent description see the ISAWIP Project Outline by Shady (1987).

Planning for this project commenced in 1982; Phase I of ISAWIP - the Basic Data Collection began in 1984; and work on main activities of Phase II, the current project, started in mid-1987 and is scheduled to be completed by 1992.

The main goal of the project is: to increase the agricultural output of the project area so that it contributes significantly and economically to national food security and agricultural production objectives. This requires reversing the deterioration in soil conditions, improving water management and facilitating the adoption by farmers of improved agricultural practices that will enable them to benefit to the fullest from the improvements in physical conditions.

The main goal is further sub-divided into three sub-objectives:

a) To improve soil conditions for agriculture by installing sub-surface drainage and carrying out soil improvement measures including sub-soiling, gypsum application and precision land levelling.

b) To improve water management for irrigation by introducing a balanced system of on-farm water management and securing the water supply during the critical demand period.

---

* Paper presented at "Reclamation, A Global Perspective," a symposium jointly sponsored by Canadian Land Reclamation Association and American Society for Surface Mining and Reclamation, held at Calgary, Alberta, August 28-30, 1989.

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c) To improve the ability of the farm population, including women, to take full advantage of better soil and water conditions through strengthened institutional linkages and integration of all project activities.

The government of Egypt is ambitiously striving to overcome a growing food deficit caused by population growth exceeding production increases. Major efforts are underway to increase agricultural production through irrigation development, installation of subsurface drains, crop improvement, soil improvement and so forth. These improvements are controlled by various government agencies working largely independently. It follows that the improvements are seldom integrated at the farm level thereby making it impossible for farmers to take advantage of their synergistic effects on yields and potential for increased income. The strategy underlying this project, therefore, was to bring together the various agencies and to make necessary improvements to overcome constraints that limit productivity — in one place at one time. The baseline conditions, improvements, and responses would all be carefully monitored. The government agencies involved would directly participate and interact in the development, and experience the predicted very positive agricultural production responses. They could then enact similar integrated improvements in other areas, having the knowledge and confidence gained at ISAWIP as a driving force.

This paper focuses on the soils and agricultural aspects of the project and stresses the need for a much more integrated approach than has been occurring to date.

The Project Area

The ISAWIP area is in the eastern Nile delta about 150 km north of Cairo and 50 km from the Mediterranean Sea. It covers a total of 33,600 ha of which some 26,300 ha is cultivated intensively. Principal winter crops are wheat, barley, beans, clover, flax and vegetables. Summer crops include cotton, rice, corn, soybeans, vegetables and potatoes.

Topography is generally flat and grades from about 4 metres above sea level in the southwest to less than 1 metre above sea level in the northeast. The area is irrigated by gravity and presently drained by a surface drainage network.

Soils are predominantly clay textured vertisols formed on deltaic deposits. Salinity affects two-thirds of the lower delta soils and is spreading. Shallow water tables (<1 m) are extensive and groundwaters are characterized by high salinity (>20,000 ppm salts). Chemical and physical characteristics of soils at the ISAWIP drainage test plots are summarized in Tables 1 and 2, respectively. The range of chemical and physical properties is considered to be representative of a large part of the project area. Exceptions include sandy areas towards the northeastern end of the project area.

Table 1. Soil chemical properties at El Genina and at El Sirw (from Wahdan et al. 1987).

		El Genina		El Sirw	
Property	Depth cm	Mean	Range	Mean	Range
EC(dS/m)	0- 30	4.1	0.9-13.5	4.9	1.2-11.3
	30- 90	4.3	1.3-10.7	5.1	1.1-11.5
	90-150	4.8	1.3- 9.4	8.6	1.1-22.0
SAR	0- 30	8.4	1.0-21.2	9.1	2.8-24.1
	30- 90	15.3	5.7-77.7	13.3	2.6-23.3
	90-150	13.6	6.4-23.2	22.0	2.7-43.5
ESP	0- 30	38.3	28.7-47.3	14.2	6.1-35.7
	30- 90	41.5	27.9-49.4	22.8	9.8-36.5
	90-150	45.6	30.0-52.8	30.9	13.7-42.6

The soils are generally fine textured and well structured. Wide deep cracks develop as the soils dry forming huge soil columns 30 cm across. Topsoils are granular while subsoils are subangular blocky grading to angular blocky at depth, with slickensides also at depth. The planar surfaces retain their identity even after prolonged flooding with rice.

Table 2. Soil physical properties at El Genina and at El Sirw (from Wahdan et al. 1987).

Property	Depth cm	El Genina Mean	El Genina Range	El Sirw Mean	El Sirw Range
Cse sand%	0- 30	1.6	0.3- 1.4	0.9	0.1- 2.6
	30- 90	0.8	0.1- 1.9	0.4	0.1- 1.6
	90-150	0.7	0.2- 2.9	0.6	0.1- 1.3
Fine sand%	0- 30	24	13-32	26	10-41
	30- 90	22	12-39	23	9-35
	90-150	19	7-28	23	12-34
Silt%	0- 30	30	17-46	33	17-50
	30- 90	34	14-48	36	23-50
	90-150	33	19-48	32	19-45
Clay%	0- 30	44	38-53	39	26-51
	30- 90	43	40-45	40	31-56
	90-150	45	38-52	44	31-61
PAW* Vol%	0- 30	25	20-31	21	17-23
	30- 90	25	19-31	22	20-26
	90-150	26	18-29	22	19-26
db* Mg/m3	0- 30	1.20	1.12-1.40	1.05	1.02-1.18
	30- 90	1.26	1.12-1.34	1.15	1.12-1.22
	90-150	1.32	1.21-1.44	1.23	1.18-1.26
DPV*%	0- 30	17	11-21	16	12-21
	30- 90	15	13-20	14	9-20
	90-150	15	11-22	15	11-18
Ks* m/d	0- 30	0.1	0.0- 0.3	0.5	0.0- 0.9

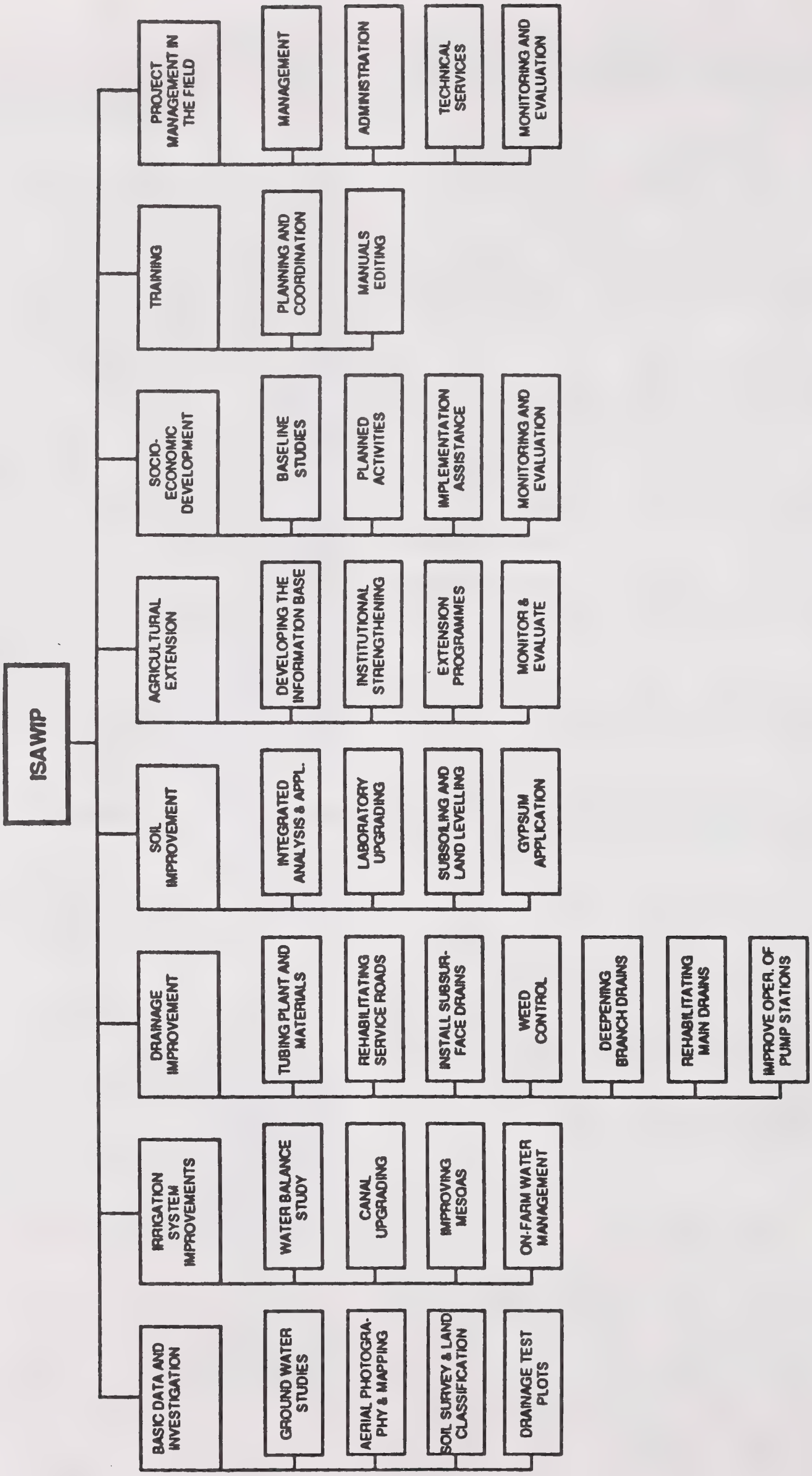
* - Plant available water (30 - 1500 kPa suction)
- Soil bulk density
- Drainable pore volume
- Saturated hydraulic conductivity

Project Components

The project consists of an integrated package of eight work components all directed towards the achievement of the project objectives. The components and estimated budgets for each are outlined in Table 3. The key elements of each component are outlined in Figure 1, the Work Breakdown Structure. To date, the proposed workplan has been revised and rewritten three times largely to reflect changing needs and schedules and the Agricultural Extension Component has been externally reviewed, in recognition of the need to expand the program. While there have been several delays in meeting targets set-out in the initial workplans, there have been many successes thus far, in terms of specialists within each component working towards their specific objectives within their respective disciplines. For example, the drainage pipe plant is built; a major purchase of computing equipment was made, operators trained and the system is operational and busy; lab equipment is being purchased to up-grade the laboratory for soil and water analysis; a number of extension or demonstration plots have been established; and so forth. Much effort has gone into collecting and analyzing data pertaining to drainage design, to improving irrigation works, to soil improvement, and to developing an agricultural extension centre, etc. There have been major questions raised and resolved, although not necessarily to everyone's satisfaction. Examples include: selection of conventional rather than modified drainage design (the latter consisting of shut-off values on drain pipe outlets to permit control of drain discharge); is there a need for subsoiling; and what are suitable criteria for gypsum application. However, integration is woefully lacking yet it remains vital to meeting the project goal of increasing agricultural productivity.

Table 3. Project components and estimated budgets.

Component	Can $ Millions	Egypt L.E. Millions
	(rounded figures)	
1. Basic data and investigations	2.1	1.3
2. Irrigation system improvement	2.1	4.5
3. Drainage improvement program	33.9	8.5
This includes:		
(Subsurface drain installation)	(20.1)	(0.8)
(Tubing plant)	(7.1)	(2.3)
4. Soil improvement	2.4	5.2
5. Agricultural extension services program	4.9	4.4
6. Social development	1.6	1.5
7. Training	1.5	0.4
8. Project management	1.7	1.5
Project Total	50.2	27.3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IMPROVING MESQAS
ON-FARM WATER MANAGEMENT
DRAINAGE IMPROVEMENT
TUBING PLANT AND MATERIALS
REHABILITATING SERVICE ROADS
INSTALL SUBSURFACE DRAINS
WEED CONTROL
DEEPENING BRANCH DRAINS
REHABILITATING MAIN DRAINS
IMPROVE OPER. OF PUMP STATIONS
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MANUALS EDITING
PROJECT MANAGEMENT IN THE FIELD
MANAGEMENT
ADMINISTRATION
TECHNICAL SERVICES
MONITORING AND EVALUATION

Figure 1. Work breakdown structure.

The project is being implemented by the Canadian Executing Agency which includes Canadian and Egyptian specialists working on a consulting basis, and Government of Egypt personnel working in their regular positions but concentrating on the project area. Consulting time allocated to each discipline is summarized in Table 4. Most of the manpower is professional and the majority of the time allocated is to be spent in Egypt.

Table 4. Executing agency manpower allocation.

Discipline	Canada: Initial Terms of Reference	Canada: Contract Terms	Egypt: Initial Terms of Reference	Egypt: Contract Terms
	person months			
Irrigation	102	92	192	135
Drainage	156	152	252	161
Soil Improvement	54	26*	60	62
Agricultural Extension	54	43*	60	66
Training	24	26	45	18
Other				
Short Term Advisors	17	included above	109	included above
Technical Support	30	22	1042	820
Procurement	18	13	132	150
Management & Admin.	91	87	60	98
TOTAL	600	477	2000	1558

* Deficiencies in these areas now recognized and extensions are under consideration.

The Integrated Approach

The initial project design and schedule provided an excellent basis for integration. Some examples of integrated activities that were or should have been done are briefly discussed next.

Basic Data Collection: The soil survey of the Phase I ISAWIP program was to provide the physical land inventory needed for planning drainage, subsoiling and gypsum application, and as a basis for agricultural extension. But, the final maps and report have not been completed to date and preliminary draft information was not made available to the project for almost one year after project start-up. In the meantime, it was necessary, for drainage design purposes, to conduct an auger hole permeability survey of the entire project area. Clearly this resulted in considerable duplication of effort. Furthermore, it cancelled an opportunity for integration between the soils and drainage components. This would not be too serious except that there are places where the findings of the preliminary soil survey maps do not match the findings of the permeability survey. One map shows deep clays while the other indicates presence of sand lenses below the surface. Why do they differ? Is it a problem of mapping intensity, or if one is incorrect how can the problem be corrected and avoided next time? These questions should be addressed. On one hand, it is not fruitful for one component to find fault with another and in an effort to encourage co-operation it is best to downplay such differences. But what happens two years later when drains are installed based on findings of one map and recommended water management for reclamation is based on another?

As a second example, early in the study it was recognized that three different agencies each produced their own maps showing cropping patterns and all were slightly and understandably different. Drainage, irrigation and agriculture each require these maps for their planning needs. The project chose to use one mapping base. This was a small but very positive first step towards integration. The second step should have been to follow through and ensure everyone involved understood why the maps differed, what the implications were to the respective agencies and what steps could be taken to improve, as necessary, mapping accuracy and efficiency in the future.

Drainage: Drainage test plots at El Genina and El Sirw were established as part of ISAWIP Phase I to test different drain depths and spacings prior to drainage design for ISAWIP Phase II.

Drains were installed, baseline soil and salinity surveys were conducted and plans were prepared for monitoring. Some five years later, it is evident that full scale monitoring did not continue. Drain discharge and water quality data were collected but irrigation inputs were never monitored. Crop yields were monitored only occasionally but other agronomic inputs such as seed quality, fertilization practice, etc. were not. Recent salinity surveys indicate that highly saline areas remain, that some drains are not functioning, that water levels at drainage outlets were often submerged, and that conclusions about optimum drain depth and spacing could not be reached. To date these test plots have been a failure in drainage. An attempt to resurrect these plots in an integrated manner in 1988 also failed. If time is taken to examine and understand why these failed so that similar problems do not arise in the large scale project then this investment might be justified. Is it safe to assume that everyone involved will do their utmost to avoid similar problems on the large scale that Phase II is implementing?

Soil Improvement: Is subsoiling or gypsum needed? Some studies in Egypt have shown a positive response to each, others have not. Soil bulk densities as indicated in Table 2 are considered normal and subsoiling to reduce compaction would not be recommended on that basis. Why the response to subsoiling elsewhere? Is it due to better drainage, better aeration, better moisture penetration, better moisture storage, different soil conditions, increases in other agronomic inputs (manure or fertilizer) due to expected improved soil conditions, or to some combination of these? The ISAWIP plan was to establish a series of test plots on different soils and under different crops to monitor the response to subsoiling and to gypsum with and without subsurface drainage. Included in the monitoring would be agronomic inputs; irrigation amounts and timing; groundwater levels; soil salinity; crop performance and yields; and soil physical conditions. While current plans are to proceed with subsoiling and gypsum application on a widespread basis using interim guidelines, the results from these test plots would enable preparation of specifications for future use. Establishment of these test plots provides an opportunity especially for the soils, agronomy and extension specialists to work together, and there is to be interaction with irrigation and drainage specialists also. Much of the field work is to be done by extension agents and as such provides an excellent opportunity for training.

Agricultural extension: Perhaps more than any other component agriculture depends on integrated technical input and in turn forwards integrated output. Extension officers need sound technical recommendations to pass on to farmers. These cover many aspects of farming including water management, soil fertility maintenance, cropping practices, credit, livestock, etc. Farming activities encompass all project components — farmers are integrators and to help increase productivity they need good "integrated" information. To reclaim saline soils and to realize the benefits of drainage, farmers need good water management advice and they must implement it; hopefully they will be motivated to do so. Drains without accompanying proper water management are of questionable value; over irrigation can lead to excessive leaching and soil degradation while under irrigating will not remove salts that reduce yields. In both scenarios precious water is not efficiently utilized, yields are not optimized and net returns are not maximized. To capitalize on the synergistic effects of improved soils and better agronomic practices (i.e. irrigation, fertilization, seeding, proper tillage, weed control), the farmers need good advice on water, soil and crop management.

To accomplish the main goal of increasing agricultural production it is our professional responsibility to ensure that the team of Canadian and Egyptian consultants along with the many Government personnel provides the full package — water management, soil and crop husbandry, farm management and so forth. A skilled and highly motivated team of extension officers is needed to market this information. Farmers need to see the potential benefits to them to enhance adoption. Note that by world standards, Egyptian farmers produce yields well above average and there is great potential to do much better.

Why The Lack of Integration

To date there has been relatively little integration of activities among components. Some important reasons, in my opinion, include:

The reductions in manpower in the agricultural and social sectors between the proposal and the contract stage created an unbalanced team and sent out a clear signal: "This is a drainage project!" No doubt there are potential benefits to installing subsurface drains. Groundwaters are high and saline, soils are saline — drainage will help. But installation of drains, at best, contributes only partially to potential for increased yields.

Much baseline data that was to be provided by Phase I of ISAWIP was either late in arriving, inadequate or incomplete. This necessitated an immediate change in priorities such that data were to be gathered, interpreted, etc. with no immediate changes in budgets or responsibilities. Not surprisingly everyone in their respective components concentrated on their main activities. A case of first we get our work done then we'll have time to integrate. Once this direction is established it is very difficult to change course. For example, initial plans called for each component to have computer mapping facilities to prepare maps that could be integrated, etc. Due to the unforeseen need for gathering baseline data, to delays in purchase and arrival of equipment, training needs, etc. it followed that the computer equipment and operators would first do the drainage design work, then shift their attention to other areas. Again, an excellent opportunity for integration lost. Another message— "the first priority is subsurface drainage!"

There have been numerous start-up problems and delays that might be considered normal for projects of this scale. In addition there have been several changes in key personnel. This contributed to delays in scheduling and changes in work plans which put more pressure on specialists and again they focused on their components, with integration being set aside. At this point there has been virtually no Canadian manpower input in the social and economics areas; agriculture is behind schedule; and the irrigation specialists will be soon completing their assignments and leaving. There is little opportunity left for integration unless there is a major funding increase or re-allocation accompanied by a serious effort at integration. Whether this might best be accomplished under the present or under a separate contract should be carefully evaluated.

Integration has not been a high priority. It has been discussed many times and its importance recognized but there has been little progress in implementation. The inability to resurrect the drainage test plots is a good example. Much effort went into preparing a new work plan that, if implemented, would provide key information essential to the agricultural, drainage, irrigation, soils and socio-economic components. It could have been a focal point for starting true integration.

The inability to integrate appears to be primarily a problem of "control". This is by no means unique to Egypt; rather, it seems to be a universal quality of bureaucracies. It seems that any one specialized agency is ready and willing to conduct studies, allocate resources, and attain success in its field, provided it is in "control". Also there is a willingness to participate in other fields provided required inputs are minimal. However it seems impossible to obtain major but more-or-less equal inputs towards an integrated "project" from say four or five agencies. It is not surprising then, that at ISAWIP where a major portion of the funding is allocated to subsurface drainage that drainage takes "control". Now the need for much more effort in agricultural extension is gaining acceptance. More funding is needed to establish a proposed Agricultural Communication Centre. However, with a limit on funding the debate is on as to whether money is allocated to the "drainage" budget or the "agricultural extension" budget. This does not bode well for integration. Whichever group is successful it will no doubt, follow through with satisfactory implementation of its "project". So what is wrong with that? The returns to investments, or yield responses to inputs will not be as great as if an integrated approach is used. This becomes even more pronounced as higher value and more productive food crops (e.g. vegetables) replace conventional crops (rice, wheat, etc.).

Recommendations

This project represents a major Canadian undertaking in Egypt. We take pride in the project's successes and good rapport we have been enjoying with our Egyptian colleagues. We have experienced some difficulties, made mistakes and neglected certain critical areas and hopefully we have learned and will improve as a result. The following points indicate areas that I believe need to be carefully examined. While this project in Egypt has been the focal point, these recommendations are intended for agricultural development elsewhere too.

A definite commitment to integration should be specified in contracts, both between countries and with executing agencies. Resources (especially money and time) should be specifically allocated to integration, for example, 20 to 30% of professional time is chargeable only to integrated activities— workshops, field projects, etc. Performance evaluations should note the integrative efforts.

The executing agencies of agricultural development projects should be required to have senior management input by Professional Agrologists. Professional Engineers, who are often in charge of such projects, do a great job on engineering aspects of the projects but they are not so successful in the agricultural areas. Senior management input from both professions would improve the balance of power and certainly increase the chances of successful integration. In this context, if Canada is serious about providing foreign aid in agriculture, we must privatize agricultural research and extension so that we could greatly increase our expertise in this area. We could reap the resultant benefits internationally and domestically. Agrologists can contribute substantially more to increasing agricultural production and also to global environmental reclamation by going beyond the bureaucratic and academic domains, into the business world. The accomplishments in land reclamation by industry as expressed in other papers at this conference clearly demonstrate this potential.

Time frames for agricultural development studies should be redefined and perhaps phases for various activities should be reconsidered. Two to five year studies are appropriate for physical or mechanical works but when human resources become an integral part of the project it is likely that more time is needed to establish contacts, develop trust, understand the subtle cultural differences and the implications to development, and so forth. Rather than trying to follow predetermined schedules work should be advanced in stages, a second phase commencing after the first is completed. There must be better documentation of baseline conditions and monitoring of performance in order to evaluate and quantify responses. For example in ISAWIP Phase II, it was estimated at the outset that the benefit/cost ratio to drainage was about 3 to 1 and to agricultural extension it was about 3.8 to 1. The cost of drainage was around $25M while the cost of agricultural extension was $5M. These benefits to improved agricultural extension are obtainable without drainage, so why not have a good extension service in place first then when drainage is installed, the synergistic effects of both could bring greater and quicker returns to the high cost investment in drainage? If drainage is installed first, and the agricultural extension is not immediately effective, then chances of successful land reclamation are reduced, indeed expected benefits to drainage may never be realized. Perhaps this is a matter of visibility. Politically and in the short term the impact of large construction equipment plowing through farm fields is certainly greater than the nudgings of extension officers, and silent adoptions of better practices by farmers. The latter though, is the key to meeting the objective of increasing agricultural production in the longer term. The ISAWIP Phase II work plan is designed to gather information to allow a quantitative evaluation of responses to various inputs, separately and together. While there have been difficulties in establishing integration in some critical areas thus far, there is still time and resources to fill these gaps and to gather the data needed to make such evaluations. Is there the will to do this? Having such information on a project basis would obviously be extremely valuable for planning, implementing and optimizing returns on future investments.

Conclusion

This project is nearly half-way through. Clearly there have been important and major accomplishments, even though they have been within disciplines — a credit to all those involved. However, there has been insufficient integration and the consequences are yet to be measured. Perhaps this is best summed up by the following quotation:

> "There might be a seed but of what
> purpose to our tomorrows and our yester-
> years to not know of the flower within."
>
> Author Unknown

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REALITIES OF UNDERTAKING RECLAMATION ACTIVITIES WITHIN THIRD WORLD COUNTRIES[1]

by

Alan R. Scheibner[2] P.Ag.

Abstract. Western Oilfield Environmental Services Ltd. (WOES) has designed and conducted environmental assessments of oil and gas exploration projects that have been carried out in third world countries. These opportunities have provided the company with an insight into the realities of attempting to use North American standards and guidelines as a basis for the development and application of reclamation techniques. This paper identifies common reclamation issues associated with seismic and exploratory drilling projects and discusses the factors that influenced their implementation in four different countries.

The mitigation factors that were encountered during the environmental assessments of exploration activities in Costa Rica, Ghana, Madagascar, and Botswana are addressed in this paper.

The development of national oil reserves is crucial to each of these countries. They are all net importers of oil, which requires the expenditure of significant portions of their Gross National Product to meet current energy needs. As these exploration programs are conducted in the national interest, regulatory control may be loosened to ensure that all available funds are dedicated to finding or evaluating hydrocarbons. The impact of this consideration and other factors, such as demographics, cultural setting and politics, on the implementation of reclamation activities are discussed.

It was observed that all of the above factors modified reclamation plans that had been based solely upon North American standards and perceptions. The author concludes that these mitigating factors must be addressed in the pre-project planning and be integrated into the design of reclamation activities if a consistent approach to reclamation issues is to be achieved.

Additional Key Words: environmental protection planning, environmental regulations, land conservation and reclamation guidelines, surface rights, construction guidelines, waste disposal, erosion control, revegetation, Third World Countries.

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[1] Paper presented at the conference Reclamation, A Global Perspective, held in Calgary, Alberta, Canada, August 27-31, 1989.

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RECLAMATION IN AUSTRALIA'S HEAVY MINERAL SANDS INDUSTRY[1]

by

Denis R. Brooks[2]

Abstract. Australia is the world's major producer of heavy mineral sands products. Responsibility for control of mining in Australia is vested in the States although the Federal Government has over-riding legislation for the environmental assessment of major projects. Each of the three states involved, New South Wales, Queensland and Western Australia, have developed different regulatory mechanisms. However, in comparison with regulatory mechanisms in America, Australian procedures are less legalistic and more flexible. Since mining commenced in 1934, the industry has mined and reclaimed landforms ranging from coastal foredunes to old inland dunes up to more than 100m in height. With the exception of some agricultural land in south-west Western Australia, most reclamation programmes have involved native vegetation and emphasis has been given to restoring functional ecosystems. Natural ecosystems rehabilitated include littoral grasslands and shrublands, heathlands, hardwood forests, and wetlands. Climatic conditions encountered include sub-tropical, moist temperate, wet and dry mediterranean. Principles for reclaiming dryland ecosystems include landform reconstruction, topsoil management, surface stabilisation, plant establishment and nutrition and monitoring of seral development. Reclamation of wetlands has additional requirements including control of ground levels, control of water levels, specific topsoil management requirements and timing. A number of reclaimed mineral sands minesites are now incorporated in National Parks.

Key Words:regulatory mechanisms, natural ecosystems, wetlands, national parks, reclamation principles, beach stabilization.

Introduction

Australia is the world's major producer of the heavy mineral sands rutile, ilmenite, zircon and monazite. Mining for these minerals in Australia commenced in 1934 on the beaches at Byron Bay, on the north coast of New South Wales (Morley,

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1981). For more than four decades, the industry was concentrated on the east coast from just north of Sydney in New South Wales to near Gladstone in Queensland (Fig. 1). This development occurred because the world's richest deposits of rutile and zircon occurred in the sand masses along that part of the coastline (Shepherd, 1986). The technology for the efficient mining and separation of the minerals was developed in Australia during this period (Morley, 1981).

Meanwhile, mining commenced in Western Australia in 1956 (Baxter, 1977). For the first two decades, operations in that state were based on the mineral ilmenite at Capel, about 200km south of Perth. In the mid-1970s, a number of operations commenced on the northern sandplain near Eneabba, about 300km north of Perth, on ore bodies containing the full suite of minerals (Shepherd, 1986).

Up until the late 1970s, Australia produced more than 95% of the world's rutile and in excess of 80% of the world's zircon. A long series of land use conflicts caused a severe downturn of activity in the eastern states (Brooks, 1986), creating a window in the marketplace to be filled by overseas operations. Whilst some operations continue in Queensland and New South Wales, the industry has consolidated in Western Australia with major investment in new mines and downstream processing. Today, Australia's share of world markets is about 54% for rutile, 62% for synthetic rutile, 50% for ilmenite, 60% for zircon and 26% for monazite. As the world's major producer, AMC Mineral Sands Ltd, a division of Renison Goldfields Consolidated Ltd, supplies between about 20% and 40% of the world's market for these products.

Regulatory Mechanisms

Mining development in Australia is

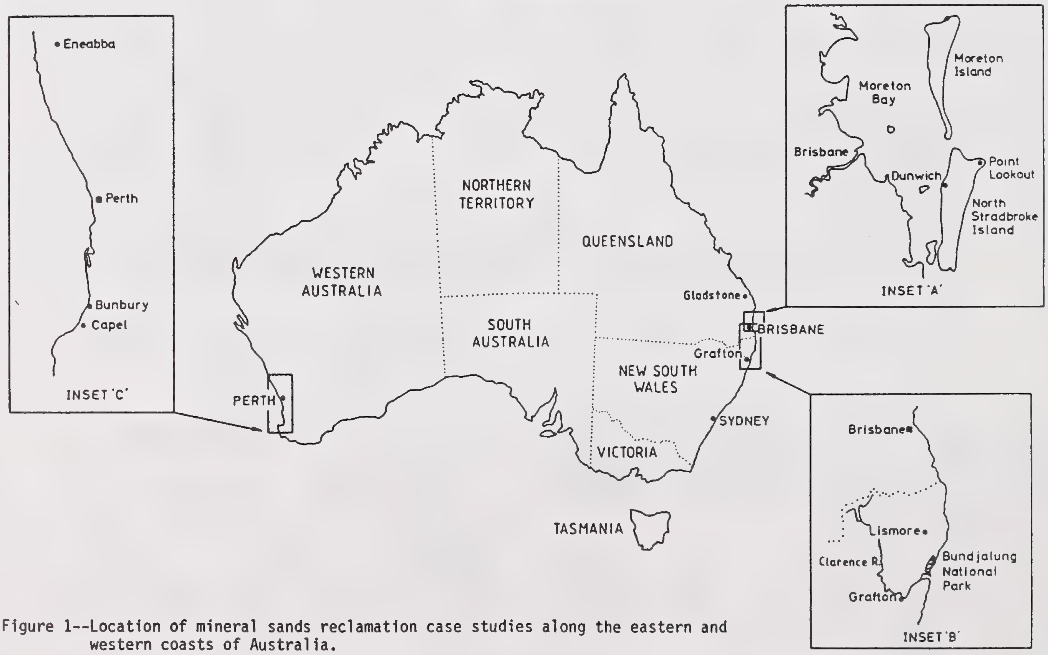

Figure 1--Location of mineral sands reclamation case studies along the eastern and western coasts of Australia.

based on the principle of Crown ownership of minerals, with a few minor exceptions. Under the Australian constitution, which is a federation of seven states, control of resources and land use is vested in the States. However, the Commonwealth becomes involved in the environmental assessment of major projects through such indirect powers as export and foreign investment controls. Whilst administrative arrangements between the Commonwealth and States have been agreed upon to deal with each Government's interest in assessment (Australian Environment Council, 1986), the potential for conflict at a political level remains. Some mineral sands projects have been thwarted by the Commonwealth refusing to grant export licences, against the State's wishes.

Procedures for the control of environmental aspects of heavy mineral sands mining, especially reclamation, vary between the states. In Queensland, controls are vested in the Department of Mines. Requirements for assessment and ongoing management of operations are set out in special conditions attached to the mining lease. The lease conditions in Queensland are the most detailed and strictest of any state. Whilst some critics argue that this system leads to less control and low standards as no specialist environmental agency is involved, its purpose is that the environmental aspects are fully integrated into the operation. The Department employs specialist officers to ensure this occurs. The operator reports to only one agency which has a full understanding of the nature and effects of operations. In practice, it is a flexible, workable system, and some of the industry's best reclamation in the world has been achieved within it.

The situation in New South Wales is complex involving a number of agencies and a rigid regulation based system. Environmental assessment of new operations is conducted by the Department of Environment and Planning, whilst responsibility for pollution control rests with the State Pollution Control Commission. The centralisation of powers within these specialist agencies often means that the officers dealing with mining proposals are unfamiliar with the practical aspects of the operations they are considering. This has led to difficulties in negotiations and to vague and impractical conditions being imposed in some circumstances. However, the Department of Mineral Resources retains responsibility for controls over reclamation, and this is generally achieved through special conditions attached to the mining lease. In this case, specialist officers within the Department deal directly with the operating companies.

Western Australia has three different legislative provisions under which mining is carried out: pre-1899 "minerals-to-owner" rights, Mining Act tenements and State Agreement Acts (Clarke and Bradley, 1987). All major mining proposals are referred to the Environmental Protection Authority (EPA) for assessment. The EPA then submits recommendations to the Government through the decision making authority, in this case either the Department of Mines or the Department of Resources Development.

Minerals-to-owner land occurs mostly within the south-west of the State and covers a number of mineral sand deposits. Environmental conditions applying to such operations can be specified in the Agreement with the landowner, through Local Government development approvals or by way of recommendations from the EPA.

Operations under Mining Act tenements are controlled by the Department of Mines through special conditions attached to the mining lease. Reclamation conditions may be changed through the tenure of the lease. Whilst this may mean that onerous conditions may be applied during the life of the mine, the system has the flexibility to deal with changes in operating conditions or reclamation technology. Again, these procedures are administered by specialist officers within the Department.

Major mineral development projects that have complex infrastructure requirements are usually developed under special State Agreement Acts. These acts facilitate the development and operation of the project, as well as providing for integrated control procedures for the Government. Mineral sands operations north of Perth operate under Agreement Acts, which are administered by the Department of Resources Development.

Under these State Agreements, environmental management, including reclamation, is controlled by the approved proposals mechanism. The Company is required to submit proposals for Ministerial approval on such matters as environmental protection, monitoring, reclamation, investigations and research. Annual and more detailed Triennial Reports are also required. Significant changes to the approved proposals brought about by changing operating conditions or technology can be made by variation procedures or through the Triennial Reports.

This system provides the necessary control mechanisms for Government and appropriate flexibility for the operating company. It is not based on detailed and complex regulations, but provides for high standards of reclamation to be achieved and maintained.

Through its operations in Florida, AMC is in a unique position to compare the regulatory mechanisms of America and Australia. The heavy mineral sands industry in America is small, though strategically important. Many of the regulatory procedures developed for mining in America, and specifically Florida, have been designed to apply to other forms of mining, and are not easily applicable to some of the unique features of mineral sands mining. By comparison with Australia, the Company has found the American system to be regulation driven, detailed and complex, rigid and inflexible. The regulations tend to restrict innovation in the development of reclamation technology, which is considered to be counter-productive. However, there are indications that the agencies are attempting to be more flexible in their approach to the mineral sands industry than previously. This trend should be encouraged as the environment will benefit in the long term.

In contrast to the American system, the Australian system is proponent driven, whereby the proponent company is required to identify the environmental effects of its operations and propose an environmental management system for approval by the Government. The system is flexible, has wide scope and encourages innovation. The proponent is judged by its corporate philosophy and commitment, thereby providing the motivation to achieve a high standard of reclamation.

Reclamation Principles

As a consequence of its development, Australia's heavy mineral sands industry has mined in a range of landforms, vegetation and climates, and developed its reclamation technology accordingly. On the east coast, major landforms mined include frontal dunes, extensive heath plains of low relief containing strand lines of late Pleistocene age, and aeolian high dunes ranging in age from Holocene to Pleistocene. Vegetation types encountered include sand spinifex grasslands of the frontal dunes, closed scrubs, sclerophyll forests, heaths and wetlands of various types. The climate varies from temperate in the south to sub-tropical in the north, although annual average rainfall is in the range of 1,100-1,600 mm.

On the west coast, the landform consists of extensive sand plains with subdued topography, possibly of late Tertiary or early Pleistocene age. Much mining has occurred on agricultural land, particularly in the south-west, although some forests have also been encountered. In the Eneabba area, north of Perth, low heathlands cover much of the mining areas. The climate is mediterranean, with rainfall ranging from 530 mm in the north to 830 mm in the south.

Thus, with the exception of agricultural land in south-west Western Australia, most reclamation programmes have involved native vegetation, and emphasis has been given to restoring functional ecosystems.

Heavy mineral sand mining has some unique characteristics that have an important bearing on reclamation. First, there is minimal volume loss, thereby allowing the landform to be substantially reconstructed. Volume loss due to product removal, of the order of 1-5%, is compensated by swellage in the tailing sand. Second, there are no toxic wastes to interfere with plant growth. The minerals are concentrated by gravity separation in a water slurry, and tailings comprise the soil components silica sand and clay or humate slime. Third, most ore bodies are shallow, so the mining is mobile and a short term land use.

These factors have enabled high standards of reclamation to be achieved around Australia. Mined out areas now have a variety of land uses including agriculture, urban development, recreation and conservation. The industry has demonstrated its compatibility with multiple land use, even with conservation.

Although each minesite has its own characteristics, the variety of ecosystems reclaimed has enabled the development of basic principles that could be adapted to each site. These principles involve the following:

1. Landform reconstruction to re-establish topographic patterns, with particular attention being given to drainage patterns. On wetland sites, re-creation of water table/ground surface relationships are critical.

2. Careful management of topsoil because of its organic enrichment and seed load. The majority of native species regeneration comes from seed contained in topsoil.

3. Surface stabilization to enable establishment of native species, seedlings of many of which are small and establish slowly. Numerous techniques are available.

4. Direct seeding of native species as the most efficient means of enhancing regeneration from topsoil, both biologically and economically. Seed should be collected from the site to ensure it is genetically adapted to the site conditions.

5. Enhancement planting of nursery raised stock, with emphasis on species that are difficult to propagate with field techniques. This operation ensures the return of species that may be important ecologically.

6. Monitoring of the seral development of the vegetation to ensure its proper development. This can range from visual inspection through to botanical sampling for a computerised data bank. Information gathered is useful for ongoing management of the reclamation.

Successful reclamation of wetland sites imposes specific requirements. From AMC's experience, a number of important inter-related principles have been developed and these are now being utilised by the Company in Florida.

First, it is essential to re-establish ground levels accurately. In this type of country, variations in contour are subtle, and changes in ground level of as little as 15 cm can have a profound effect on drainage and vegetation patterns. Therefore, control of tailings placement by operations personnel is critical and needs to be carefully planned.

Second, drainage of the area before and after mining is essential. Prior to mining, surface water needs to be removed to enable the topsoil to be stripped in moist though not sloppy conditions. Otherwise, saturated topsoil would cause a loss of viability of propagules following disturbance. Drainage of the site following mining is also important so as to keep the water levels at or below the ground surface whilst the vegetation re-establishes. During summer months, wetland vegetation can suffer scalding from inundation in the establishment phase as shallow surface water heats up. Drains can be removed once the vegetation has gained sufficient height and maturity to cope with inundation. Experience has shown that wetland vegetation establishes and grows best during dry weather, when water levels fall below the ground surface and soil moisture is still adequate.

Third, topsoil handling procedures are critical because a high proportion of wetland vegetation can recover from vegetative propagules in the soil. Not only is moisture content important, but the topsoil needs to be handled carefully by the bulldozer operators. At one of the Company's sites, a double stripping method was developed in order to minimise disturbance to the soil and damage to the plant propagules. The top 20-25cm was removed in slices by the bulldozer so as to retain the soil and plants in large lumps, and stored to one side of the mine path. A further 10-15cm was then stripped and stored separately. Immediately after the mining plant had returned the tailings to the mine path, the topsoil layers were returned to their respective positions. The topsoil storage time was governed by the rate of forward progress of the mining plant, but was of the order of 1-3 months.

Fourth, timing of reclamation operations is critical, especially contouring of tailings and return of topsoil. In wetland sites, the mining operation itself provides the best opportunity to control the large volumes of water involved. Any delay to reclamation procedures will increase the probability of local flooding from heavy rainfall which will result in reduced regeneration success. Therefore, mining operations of wetland sites need to be carefully planned and conducted to take account of the particular site conditions and reclamation requirements.

Lastly, the application of a moderate dose of mixed fertiliser shortly after topsoil return will boost vegetation recovery. The Company's experience has shown that species richness and growth rate will increase, resulting in a balanced plant community. Also, the regenerating vegetation will be vulnerable to adverse conditions for a reduced period of time.

Case Studies

To illustrate the development and application of these principles, a number of sites mined and reclaimed by AMC are discussed below.

Frontal Dunes

Although a number of frontal dune sites have been mined and reclaimed by AMC and other companies along the coast of New South Wales and Queensland, the largest programme occurred on North Stradbroke Island in southern Queensland (Fig. 1). A total of 32 kms of frontal dunes was mined and reclaimed. The scale of the project provided the basis for considerable development in frontal dune reclamation technology (Brooks, 1976, 1980; Brooks and Bell, 1984), with attention being paid to reconstruction of natural ecosystems.

Before mining, the dune system was largely unvegetated and unstable. Wind erosion carried large volumes of sand landwards away from the beach system, progressively burying a freshwater swamp behind the dunes. During storms the beach and dunes were further eroded by wave attack.

The first prerequisite of reclamation was to construct a stable dune landscape. This involved creating a moderate frontal slope (10 to 15°), a well defined dune crest and a varied topography to allow the development of a range of microhabitats. The planned placement of tailing sand using the hydraulic stackers at the rear of the mining plant enabled the desired landscape to be constructed at minimal cost. It was also possible to move large volumes of sand towards high water mark, thereby returning the sand to the beach system.

The second prerequisite was to commence stabilization at high water mark to prevent windblown sand from the beach burying establishing vegetation. Where sand spinifex grass (*spinifex sericeus*) remained on remnant dunes, fertilisation of the grass dramatically improved dune stability. In the absence of remnant dunes, sand trap fences had to be constructed. Whilst a range of materials can be used for these fences, artificial mesh fences were used mainly for greater efficiency (Brooks and Bell, 1984). Sand trapped by these fences ultimately formed new dunes when colonised by adjacent vegetation (Brooks, 1980).

The vegetation sown on these frontal dunes was endemic to these situations to withstand the rigours of wind, sand and saltspray. Sand spinifex grass was the mainstay of the programme, although other species were also used to increase plant diversity, especially in certain microhabitats. Techniques were developed to harvest, process and sow large quantities of sand spinifex grass seed, as well as to establish a stable vegetative cover on a large scale. Following the establishment of the grass cover, a range of tree and shrub species were introduced from the Company's nursery.

Stabilization of the surface was critical to enable the vegetation to establish. Given a ready source of supply, brush matting proved to be the most effective material for this purpose, although alternatives included stubble mulch and chemical stabilizers (Barr and McKenzie, 1976).

During the landscape reconstruction, a number of depressions were formed in the dune system, many of which intersected the ground water table. Techniques were developed to stabilize and reclaim these sites as wetlands using the rhizomatous sedge Carex pumila (Brooks, 1988a). The natural recolonization that followed (Fig. 2) provided opportunities for the study of successional development of new wetland ecosystems. It appears that birds and other animals were the main dispersal mechanism for the colonising plants.

The use of the techniques described created a diverse habitat on the newly stabilized dune system. The natural sand accretion/erosion processes also re-established within the beach zone. International experts have described this project as the best of its type in the world (Bradshaw and Chadwick, 1980; D.N. Ranwell, pers comm).

High Dunes

The high dunes of eastern Australia are described by Thompson (1983), and are characterised by massive soil profile development over time (Thompson, 1981). Whilst high dunes have been mined at Myall Lakes and Fraser Island, North Stradbroke Island is the main centre of these operations. Mining commenced in the high dunes of North Stradbroke in 1966 (Morley, 1981, p.154) and continues today. Much of the relevant reclamation technology was developed there (Brooks, 1976; Brooks and Bell, 1984).

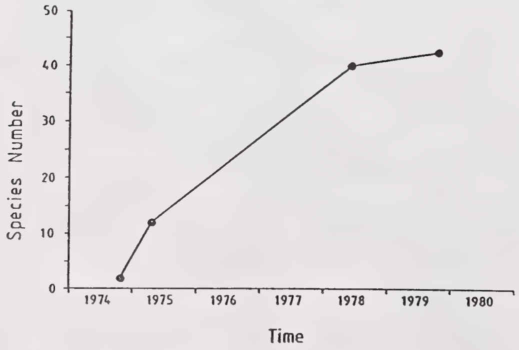

Figure 2 - Natural colonization over time by aquatic macrophytes in an interdunal wetland on North Stradbroke Island, Queensland.

Most of the reclamation effort on high dunes goes into landscape reconstruction. Dunes up to 100m in height have been re-built using hydraulic stackers and land lines fitted with booster pumps. As the organically enriched topsoil is responsible for over 90 per cent of the seed source of regenerating vegetation, its recovery from areas to be mined and subsequent replacement is critical. The options for topsoil management on these massive dunes are limited, and basically come down to engineering considerations. Storage of topsoil for periods of three years has been necessary and does not appear to have adversely affected the success of reclamation of this vegetation.

Seed of the tree and large shrub species fail to survive topsoil handling or are absent from the topsoil (Brooks and Bell, 1984). However, observations in 1973 revealed that these species readily regenerated from seed carried in with brush matting used to stabilize the soil surface (Brooks, 1976). It was concluded that direct seeding of these species could be a useful technique, and a major seed collection programme was initiated. Techniques were developed to direct seed these native species both at the initial establishment phase and at later phases when it was desired to upgrade previously established vegetation (Brooks, 1987).

The direct seeding techniques have been highly successful. Carey and Brooks (1985) found that densities of the upper canopy species up to ten fold greater than pre-mining densities have been attained, providing ample allowance for attrition caused by competition and suppression of slower growing individuals. Consequently, the dependence on nursery stock has been greatly diminished.

Sowing of low density cover crop has become standard practice to assist surface stabilization and provide some protective cover during the first 12 months whilst the native species are establishing. Moderate quantities of a mixed fertiliser have been applied routinely with the cover crop to aid its establishment and partially compensate for losses of macro-nutrients in the mining process. A great deal of consideration has been given to the use and fate of applied fertiliser because of fears of phosphorus toxicity in certain species (Brooks and Bell, 1984). However, studies revealed that increased species richness and plant density resulted from moderate levels of fertiliser under reclamation conditions.

In addition to cover crops, other methods of surface stabilization have been necessary to promote the regeneration of native species. Brush matting has been used extensively for this purpose, as it has the advantage of introducing significant quantities of seed in certain circumstances (Brooks and Bell, 1984). However, Barr and McKenzie (1976) found that chemical stabilizers were an effective and less expensive alternative. Terolas ®, a bituminous compound applied in a water emulsion, has been widely used.

The seral development of the vegetation has been described in detail by Brooks and Bell (1984). Investigations are in progress on the role of endomycorrhizal fungi and Rhizobium bacteria in undisturbed and regenerated vegetation and their reintroduction where necessary.

Studies on fauna in rehabilitation have been limited to ants because of their usefulness as bio-indicators of vegetation status. In a survey on North Stradbroke Island, Majer (1984) found that ant recolonisation proceeded rapidly in the early years of regeneration. In a related study, ant activity, as indicated in ant-seed relationships, recovered quickly on rehabilitated ground (Majer 1985).

The full recovery of the ecosystems on the high dunes will, of necessity, take a long time. Whilst the preliminary studies are very encouraging, further investigations are warranted. Indeed, many opportunities for additional research exist. However, Rogers (1982) was able to conclude that the complete ecosystem is being re-established.

Coastal Lowlands

Many mineral sands ore bodies on the east coast occur as ancient strand lines underlying extensive heath plains referred to as coastal lowlands. The topography of these lowlands is subdued with complex drainage patterns giving rise to a mosaic of dryland and wetland vegetation associations. Typical vegetation types include low dry open forests and shrublands, dry heaths, wet heaths, sedgelands and swamp woodlands.

One such area occurs on the north coast of New South Wales at a location known as Jerusalem Creek, now in the Bundjalung National Park. Since it was discovered in 1890, mining has had a checkered history here (Morley, 1981). Large scale operations were conducted by AMC from 1969 to 1982 over an area of about 13 square kilometres. From 1974, the Company mined on low lying country supporting a variety of wetland vegetation associations. On this landform, the water table is typically at or above the ground surface for 4-6 months of the year, falling below ground level during the dry late winter-early spring months. The vegetation type is governed by moisture relationships, with wet heaths being slightly higher and inundated for shorter periods than sedgelands. Swamp woodlands carry surface water at all times except droughts.

Techniques for rehabilitating these wetlands were developed from hard experience. Early attempts were thwarted by a series of flood events. Vegetation attempted to regenerate from rootstock and seed in the replaced topsoil a number of times. On each occasion, the young vegetation was killed by scalding because of warming of the shallow surface water following heavy rains during summer months. Finally, about two years after the initial topsoil return, a short-term drought allowed the water table to fall below the surface and enabled freshly regenerated vegetation to develop above the height of normal water levels. The vegetation has since continued to develop satisfactorily.

From this experience, the principles for reclaiming wetland vegetation were developed. Subsequent experience has shown they are applicable to all wetland vegetation types encountered so far.

Application of fertiliser had a significant effect on the regenerating vegetation (Brooks, 1988a). As early as age 16 months, fertilised wet heath vegetation had a higher species number, percent cover and abundance than unfertilised heath (Table 1). The increase of species number over the pre-mining level was caused by the topsoil disturbance stimulating seed of species lying dormant in the soil. These species were often short-lived pioneers.

Table 1.--Response of reclaimed wet heath at Jerusalem Creek to fertiliser at age 16 months (from Brooks, 1988a).

	FERTILISER	
	-	+
Species Number	25	39
Percent Cover	1.2	34.9
Abundance	1.15	5.27
Species Number Pre-Mining	34	

The effect of the development of topsoil handling techniques was demonstrated in the regeneration of a key species in this vegetation, _Xanthorrhoea resinosa_ subsp. _fulva_. This species is a multi-crowned shrub with an acauline habit and considered difficult to regenerate following disturbance. Double stripping of the topsoil gave rise to a large response compared with single stripping (Table 2). As the disturbance stimulated the plants to flower within three years, there was the potential to further increase the population of the species.

The adoption of the reclamation techniques described enabled the various vegetation associations, including swamp woodlands, to recover rapidly and successfully. The mined area was incorporated in the Bundjalung National Park following the cessation of mining in 1982. The area is also listed on the Register of the National Estate. In considering that registration, the Australian Heritage Commission formally congratulated the Company on its success in re-establishing native ecosystems.

Wetlands in the South-West

A unique opportunity is being taken in the south-west of Western Australia to implement a project

Table 2.--Recovery of crowns of Xanthorrhoea resinosa subsp. fulva from different topsoil handling regimes at Jerusalem Creek (from Brooks, 1988a).

	SITE 1	2	3	4	5
Density (crowns per hectare)	430	670	110	1,970	6,540
Age (year)	3	3	2	2	1
Topsoil Storage Time (months)	1-2	3	1-2	1	1-2
Stripping Method	Single	Single	Single	Double	Double

after mining specifically for the purpose of waterbird conservation. The Company has been mining at Capel (Fig. 1) since 1956. Part of the ore body was very high grade in ilmenite, and the removal of this mineral caused a significant volume loss. This volume loss was accounted for by creating a system of lakes in worked out pits that intersected the water table. The main lake system, consisting of eight lakes with a total water surface of about 44 hectares, was formed during mining between 1975 and 1979.

The majority of the lakes occur within a State Forest which previously supported a pine forest of low productivity. After mining, the foresters have taken the opportunity to adopt a multiple land use plan involving forestry, recreation and conservation.

In 1984, the Company commissioned the Royal Australasian Ornithologist's Union (RAOU) to advise on the potential of the lakes for development of self-sustaining wetland ecosystems for the purpose of waterbird conservation. Following a favourable report, the Company initiated a wetlands project by establishing the AMC Wetlands Centre in 1986.

A Management Committee has been established for the Centre to advise the Company on objectives and priorities, management and research proposals and budgets, and to review progress. Through its membership the committee taps the main expertise and responsibilities for wetlands and waterbird conservation in the state, thereby forging links with appropriate Government authorities, and research and conservation institutions. There is representation from the Company, RAOU, Department of Conservation and Land Management, University of Western Australia, Murdoch University and Curtin University of Technology. The RAOU has been engaged as Project Manager.

The objectives of the Centre are:

1. To develop self-sustaining wetland habitats for the conservation of waterbirds;

2. To conduct research into wetland ecosystems, their development and management;

3. To develop opportunties for public education and recreation; and

4. To develop and demonstrate wetland reclamation technology.

One of the first steps in the project was to initiate a series of multi-disciplinary baseline studies to determine the current ecological status of the lakes and to indicate priorities for future research and development. Nearby natural wetlands were used as control sites. These studies confirmed the potential of the lakes for their development as self-sustaining ecosystems, whilst indicating the limitations of the undeveloped habitat in supplying food and shelter for the waterbirds (Brooks, 1988a). The need to increase the productivity of the lakes through habitat development was highlighted.

With the benefit of these studies, a long-term conceptual plan has been developed for the Centre. It is planned to create a variety of habitat types to provide refuge for a large range of waterbird species on these permanent freshwater bodies. The plan also involves the development of education and passive recreation facilities in keeping with the multiple-use concept for this zone of the State Forest integrating conservation, recreation and education with nearby forestry. A visitor's centre is planned with parking and picnic facilities. A number of walking trails will be developed incorporating a series of hides and viewing towers at strategic locations.

Site development works commenced during the 1987/88 summer to enhance the limited habitat range by providing feeding, breeding and loafing sites for the birds. The work programme includes earthworks to create channels, moats and islands, land-scaping of banks, mass plantings of wetland trees, shrubs and emergent vegetation, construction of wave barriers and artificial floating islands, and installation of nest-boxes. These works will continue over a five year programme.

An ongoing research programme is an integral component of the project. The programme integrates studies of wetland development and waterbird ecology, with particular emphasis on the food chain. There are studies on sediment/water/nutrient inter-actions, vegetation, algae and diatoms, invertebrates, frog and reptile recolonisation, bird diets, breeding patterns, and the pattern of usage of the developing ecosystem by birds. The project will have obvious benefits in wetland conservation, particularly in view of the loss of natural wetlands in south-west Western Australia. The multi-disciplinary nature of the research programme, integrated by the Management Committee, is a key attraction to scientists working at the Centre. The project will increase understanding of wetlands, and will also help to develop and demonstrate the technology for the reclamation of wetlands. It is believed that the project is unique in Australia.

Northern Sandplain

Mining on the northern sandplain of Western Australia has centred on heathlands on Vacant Crown Land and Flora and Fauna Reserves south of Eneabba (Fig. 1). The vegetation consists of low shrubland with a high level of species richness and endemism, and a low order of dominance. A vegetation survey on an area of 20km^2 covering the ore bodies recorded 429 species (Hopkins and Hnatiuk, 1981), 15% of which could not be identified to species level. A total of 50 families and 162 genera were represented in the survey. About 10% of the species recorded were classified as rare or poorly known. Thus, the vegetation is complex and of outstanding diversity and significance (Lamont, Hopkins and Hnatiuk, 1984). Little is known about many of its components, and a number of species are difficult to propagate.

The Eneabba climate is harsh, and is characterised by long, dry, hot summers, with temperatures often exceeding 40°C. Average annual rainfall is about 530mm, and rainfall exceeds evaporation only during the months of June, July and August (Hopkins and Hnatiuk, 1981). Hence, the growing season is short and discrete. Conditions during the summer months are aggravated by frequent strong easterly winds. Reclamation at Eneabba follows the same basic principles used on the east coast, i.e., return of topsoil, surface stabilization including the use of mulch, cover crops and fertiliser, and propagation of native species by direct seeding and planting of nursery stock. The main task is to adapt these principles to the local climate and vegetation. A comprehensive research programme is in progress involving soils, plant nutrition, flora, fauna and micro-organisms (Brooks, 1988b).

The main thrust of the reclamation programme focusses on various techniques to propagate this complex flora. Generally, the plant species can be classified into two broad groups, viz, soil stored (seed stored in topsoil) and bradysporous (seed stored in woody fruits within the canopy).

Again, management of the topsoil is a key issue because of its importance as a seed source. Stripping and spreading of topsoil in two layers has enhanced regeneration of the native species, with the seed laden top layer being spread to about 2.5 cm depth. Storage of the surface layer is restricted to less than 12 months to aid vegetation recovery. Monitoring studies reveal that regeneration of soil stored species continues over a number of years (Carey and Jefferies, pers comm).

Standing vegetation on the mine path is mulched and spread on land being reclaimed, partly as a stabilization technique and partly as a source of seed. Mulch contributes significantly to the species richness and density of regenerating seedlings, and establishment from this source usually occurs within two years (Carey and Jefferies, pers comm).

Considerable attention is given to seed collection and direct seeding of a wide range of species, a typical seed mix consisting of about 100 species. However, a number of difficulties arise. Many species produce limited quantities of seed or produce seed of poor viability (Carey and Jefferies, pers comm). Seed quality varies greatly from year to year in some species. Hence, germination testing of seed lodged in the seed store is becoming routine practice as data on the germination requirements of these species becomes available.

Field research has shown that time of sowing has a significant effect on establishment of the native species (Osborne, Lloyd and Brooks, 1986). May is the optimum sowing time and this coincides with the normal commencement of winter rains. Therefore, all field establishment procedures are planned to be completed by the end of May.

As a support of the field establishment procedures, the Company produces seedlings in its own nursery. Seedling production is restricted to those species which are difficult to propagate in the field or for which limited seed is available, and which are considered to be important elements of the vegetation. The nursery has a capacity of 70,000 seedlings. Planting out occurs as soon as soil moisture reserves are replenished, usually in June/July. The seedlings depend entirely on rainfall for their moisture supply, despite the limited growing season.

Because much of the mining to date has taken place in a Flora and Fauna Reserve, the Government has adopted quantitative standards to assess the success of reclamation. Parameters assessed include species richness, plant density and canopy cover. The Company has developed an electronic botanical data management system to collect and process data on the seral development of the vegetation from its monitoring programme (Brooks and O'Neill, 1987).

Data from this programme have shown the results of the development of reclamation techniques in recent years. Plant densities for first year reclamation blocks has risen from less than one to more than seven plants per square metre from 1981 to 1987 (Carey and Jefferies, pers comm). Although the Government's standards have yet to be achieved, a number of reclamation blocks are expected to reach them within a few seasons. Certainly, areas reclaimed in recent years are starting with a much stronger establishment base than those reclaimed in earlier years. It is considered that meeting these standards will be a significant achievement on what is arguably the most difficult site the mineral sands industry has had to reclaim anywhere in the world.

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ASPECTS OF LAND RECLAMATION IN INDIA, SOUTH AFRICA AND SPAIN[1].

by

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Abstract. The reclamation of land disturbed by industrial and construction activities in India, South Africa and Spain provides for many contrasts between each country.

In Spain, land reclamation is a virtually new concept, imposed by the country's recent entry into the European Common Market and the need to conform with the environmental regulations of the EEC. Consequently, there are few examples of actual reclamation in mining and other industries. Much is still at the assessment stage of environmental problems and the planning of land reclamation.

India has long recognised the need for land reclamation but this has been limited by economic, socio-cultural and technical restraints. Industrial development has had catastrophic effects on the nation's forest cover. Recent legislation has recognised the situation, and, as a result, all new mining leases which entail the destruction of reserved forests, must afforest an equivalent area of non-forest land in addition to the reclamation of the mine site itself. Afforestation must begin to take place immediately, not just at some time into the active life of the mine.

Reclamation in South Africa gained worldwide recognition with the development of procedures to establish vegetation on steeply-sloping acidic gold tailings. Less widely known are the subsequent modification of those procedures. Reclamation of other metallic wastes, coal spoils and overburden is common practice. Several intensive reclamation research programmes are underway.

Some of the problems and successes on land reclamation in each of the three countries are described; the legislative status of land reclamation, and the effect of economic, technical and social factors on land reclamation are briefly reviewed.

Introduction

Climatic and edaphic factors primarily determine the type and form of land reclamation programmes. Socio-economic and legislative factors in any one country though, may determine whether or not disturbed lands are actually reclaimed, the rate at which land is reclaimed, and reclamation standards (i.e. permitted level of environmental impact of the industrial activity).

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One of the major obstacles to developing revegetation programmes on mining and industrial wastes and subsoils exposed by construction activity, is the concept held by many in industry and government that a green cover, quickly established, is all that is required for successful reclamation. In South Africa, such a cover would consist entirely of grasses, usually composed of two or more of *Cynodon dactylon*, *Eragrostis curvula*, *Chloris gayana* and various other species. The long term relationship between these species has rarely been considered despite clear evidence that unmaintained stands of such species decline in time and lose their effectiveness for erosion control On occasion, alfalfa would be included as a legume component, but with virtually no chance of success because of interspecific competition.

One research programme (Walmsley, personal communication) is now investigating the use of more balanced grass-legume seed mixtures in order to establish maintenance-free vegetatation and at the same time permit the invasion of local species. As well as evaluating tropical legumes, such as *Desmodium inortum* and *Macroptilium atropurpurium*, a number of temperate legumes are being seriously considered for tailings revegetation and elsewhere. Several trials conducted by the agricultural industry have indicated a strong potential for *Lotus corniculatus*, *Coronilla varia*, *Onobrychis viciaefolia*, *Ornithopus sativus* and *O. compressus* in certain regions of the country. Greenhouse trials utilising tailings from various sources have given an initial indication of satisfactory adaption but field trials are required for confirmation.

The above approach strongly contrasts with that of another research programme (Wyk, personal communication) which is a evaluating a very large number of ecotypes of *Eragrostis curvula* for use in land reclamation. Traditionally, *E. curvula* has been widely used in South Africa as an erosion control species, despite obvious limitations imposed by growth habit and lack of longterm persistence. The programme not only hopes to overcome those characteristics, but to provide sufficient seed of single or bulked ecotypes for use in large scale reclamation programmes.

Although revegetation of gold tailings has dominated the land reclamation scene in South Africa for many years other tailings and wastes are rapidly emerging as major fields of activity. Little publicised, but undertaken with great success over the past decade, has been the restoration of mineral sands at Richards Bay in Natal. The restoration of wastes arising from the mining of platinum, asbestos and coal are now receiving great attention. The number of environmental impact assessments being undertaken by various consulting companies are indicative of this.

One technical aspect of land reclamation that will have to be addressed in the near future is the limited (type and quantity) availability of grasses, legumes and herbs for use in erosion control schemes. Only one perennial legume is widely available at present- alfalfa. There has been no development (and given the apparent lack of a market for such this is understandable) of herbaceous species for use in the arid and semi-arid climates which characterise much of the Iberian Peninsula. Where reclamation schemes have been undertaken on highway and other areas, landscape-type shrubs and trees have mostly been used.

Reclamation Practice in South Africa

The reclamation of land areas disturbed by mining, highway and other construction and industrial activity is widespread and accepted practice in South Africa. There is a large literature base spread between research publications, government documents, institutional magazines and conference proceedings. Because of the enormous importance and influence of mining on the South African economy, descriptions of mined land reclamation, and associated technology, tend to predominate. (e.g. Gowan and Williamson 1987; Smith, Bentel and Robbertze 1987; Walmsley and Jones 1987; Wells 1987; Wrench 1987; Wyk 1979, 1988; Wyk, Wells and Marsden in press)

The success achieved by the gold-mining industry in South Africa during the past 25 years with the establishment of vegetation on acidic gold residue deposits has been considered outstanding by many reclamationists. A history of the technical development and the respective contributions of the various people involved over the years has been compiled by Marsden (1987), while changes to some of the original techniques, leading to an improved ecosystem development on the deposits owned by Rand Mines, have been described by Wells (1987).

Many of the earlier vegetated deposits now exhibit a vegetative cover clearly in a slow decline. No maintenance fertiliser, frequent fires and human activity have largely contributed to the decline. In contrast, on those older deposits subjected to selective fertilisation practices and land management there has developed a diversified plant cover, including invasion by local species, capable of recovering from fire and requiring only minimal maintenance. In addition to newer revegetation techniques, specific close-out procedures for recently completed residue dumps have been devised, especially control of water run-off, which contribute greatly to the success of new reclamation programmes.

Land reclamation in India primarily involves the re-establishment of forest cover, whether on or off the mine site, by the planting of container grown tree stocks. Some of the most commonly used species include *Eucalyptus*, *Cassia*, *Acacia*, *Prosopis*, *Azadirachta*, *Lucaena* and *Dalbergia*. Given the wide range of climates which occur in the Indian subcontinent, this list of species is by no means exhaustive or wholly typical.

In the arid area of Rajasthan, grasses, *Cynodon dactylon* and *Pennisetum typhoides*, have been successfully established on zinc-lead tailings along with several shrubby ornamentals including *Lantana* species (Chaphekar 1989). This use of grasses, however, appears to an exception to general revegetation practice.

Reclamation Practice in Spain

Land reclamation in Spain has yet to develop as a vigorous activity in academic, government or industrial circles. There are a number of reasons for the current state of affairs.

The relevant legislation is comparatively new, it does not apply to already existing situations (unless having severe impact upon air and water quality in which case government persuasion can be brought to bear), industry is waiting to see what degree of enforcement will be applied by government, and there are few reclamation specialists to provide advice to either industry or government.

There are other reasons as well. For example, in the aggregate industry, many operations are small and individually owned. Although the collective environmental impact of aggregate mining in any one area can be quite large, each of the individual operations cannot afford to undertake either reclamation or EIA studies. Also, Spain at present has high unemployment, and the government appears loath to enforce environmental regulations which may result in a reduction or closure of a mining operation.

There is virtually no published information available and much remains hidden within company or government reports; for example, the extensive reclamation work undertaken by Asturiana de Zinc at its Reocin mine in northern Spain, revegetation trials on old metal mines undertaken by the regional government of Murcia (southern Spain), and an environmental impact assessment of kaolin mining (Minconsult 1988).

reclamation procedures and technologies in other countries. As a result, much of the investigative work undertaken in India is either repetitive or reveals a lack of technical understanding for some of the basic procedures in revegetation work, e.g. legume inoculation, fertiliser requirements, species selection and adaptation trials. [

At present much of the reclamation work in India is descriptive, making assessments of current environmental problems (but often based on minimal air, soil and water data collection) and drawing up environmental management and reclamation plans for the future. This state of affairs is partly due to the requirements of the current legislation. Environmental management and land reclamation plans are required from mining companies if they are to obtain licences to mine; particularly, where the destruction of forested land is involved.

A licence will only be granted if the company can demonstrate that it has an equal amount of non-forested land elswhere that be afforested almost immediately. This is known as compensatory afforestation. If only degraded forest land is available, then twice the number of trees have to be planted on that land. The afforestation policy has been criticised (Rao 1989) on the premise that it has no value in terms of ecological balance, and,"if damage is done to the foot, one does not treat the arm.. damage to nature at place A is not rectified by rehabilitation or afforestation at place B".

After a mining licence has been granted by the regulatory authorities, there is virtually no inspection mechanism to ensure that the environmental and reclamation programmes designed for a mine site are actually carried out, or if so, are of a satisfactory standard. This situation is proposed to be rectified shortly by the establishment of a national environmental monitoring agency.

In the meantime, the degree of land reclamation undertaken by mining companies is dependent upon the environmental ethics of the companies. There are a number of private companies which have undertaken large and elaborate land reclamation schemes. One especially worthy of mention is Sayaji Iron and Engineering in west-central India; where the standard of restoration (to wild-life habitat) is the equal of many elswhere in the western world. Unfortunately, but not altogether suprising, the attitude of some private and government owned mines towards land restoration leaves much to be desired.

A discussion of the many technical problems associated with land reclamation in India cannot be undertaken here for reasons of space. It must be sufficient to say that the problems of controlling surface erosion and sediment runoff, of lack of overburden and tailings characterisation studies and of little attention being given to post-mining landforms in open-cast coal mining, represent only a few of the many problems that have to be resolved within the Indian mining industry.

1. The location of residue deposits and evaporation ponds for liquid wastes;
2. The disposal of wastes in any way other than on residue deposits and in evaporation dams;
3. Safety of residue deposits;
4. Prevention of environmental pollution;
5. Maintenance of abandoned residue deposits;
6. Specific requirements in respect of coal discard or debris;
7. Hazardous waste (non-radioactive and radioactive materials.

Both the above authors have stated that the regulatory structure appears quite complex; yet equally point out that the structure works well in practice. The various acts are supplementary to each other and satisfy the requirements of the relevant controlling authority.

In addition to the various acts and regulations, the mining industry provides self-regulation in environmental protection through its representative body, the Chamber of Mines. That organisation has produced a series of "Handbooks of Guidelines for Environmental Protection" and include recommendations and procedures for the reclamation (revegetation) of gold and coal wastes.

Reclamation Practice in India

Land reclamation in India has traditionally been associated with the reclamation of saline and sodic agricultural soils (e.g. Abrol 1986). Only within the last decade have there been numerous attempts to restore lands disturbed by mining to an acceptable or useful vegetative condition (e.g. Gupta 1979; Mann and Chatterji 1979; Prad and Chadhar 1987).

A recent conference (Federation of Indian Mineral Industries, 1989) revealed the extent of activity in the reclamation of lands disturbed by mining during the last decade but at the same time demonstrated several weaknesses in the land reclamation scene. The results of the above activity have either not been published,or if so, only in government or industry reports to which access is difficult to obtain. Also, many of those active in land reclamation have had little or no opportunity to review or study the development of land

The Mineral Concession (Amendment) Rules, 1960, amended 1987 and 1988, prescribes, among other, the detailed contents of theMining Plan, qualifications of the persons recognised to prepare the mining plan and the obligations of the mining applicant regarding the compensatory afforestation and implementation of the mining plan. In order to encompass the provisions of the Water Act, 1974, the Air Act, 1981 and the Forest Act, 1980 and other constituents of the environment not included in those Acts, the Environmental (Protection) Act, 1986, (and the rules framed under it in 1986 and 1987) was enacted as an umbrella environmental act. The new Act is a more comprehensive piece of legislation than any other legislations enacted earlier which contained only limited provisions regarding the environment.

The Forest (Conservation) Act, 1980, provided for the conservation of forests by controlling the indiscriminate diversion of forest land for non-forest purposes. The amended act was introduced to provide a greater degree of control over the leasing and clearing of forest land for non-forest purposes. In particular, the definition of what constituted non-forest land use was refined to include therein the cultivation of plantation crops, oil-bearing plants, horticultural crops and medicinal plants.

Despite the above legislation, there is still no specific legal requirement that a coal company must reclaim or restore the topography or former ecological values of a mine site (Town and Country Planning Organisation 1987, Annexe V, p.42.). Also, as pointed out by Bannerjee (1988), the coal company has no incentive to restore the disturbed mine site, for, after use, the land reverts to the government, and there is no economic incentive to the company to undertake progressive land reclamation.

Reclamation Related Legislation in South Africa

The regulatory structure for the control of hazardous waste (including mining wastes)in South Africa was briefly reviewed by Malan (1987). Control measures are included in different acts, ordinances and by-laws which control environmental conservation in total. There are presently six Acts of Parliament in force which either directly, or through regulations, control mining waste management (Wyk, Wells and Marsden, in press).

The aspects of mining waste management which are governed by the six acts (with two further acts pending) have been described by Wyk, Wells and Marsden (in press) and are as follows:

TABLE 1. CIRCUMSTANCES REQUIRING OPEN-CAST MINING EXTRACTION INDUSTRIES TO CONDUCT AN ENVIRONMENTAL IMPACT ASSESSMENT.

1. Operations requiring a total earth movement of more than 200.000 cu. m./annum;

2. Operations carried out below a water table, the reference level being the highest level known in in the annual fluctuation cycle;

3. Mining of fluvial, fluvioglacial, coastal or wind dynamic deposits, and marine deposits;

4. Mining operations visible from motorways, divided highways, national and regional roads, from urban centres with more than 1.000 inhabitants, or those which are situated less than 2 km from such centres;

5. Operations located in protected natural spaces or in an area which can be seen from any of its established boundaries;

6. Mining of substances which may be altered by oxidation, hydration, etc., and which may induce limits in excess of those contained in current legislation for acidity, toxicity or other parameters in concentrations which involve risks to human health or the environment, e.g. ores with sulphides, mining of solid fuels, those requiring leaching treatment *in situ*, and radioactive minerals;

7. Operations which, while not coinciding with any of the above circumstances, are located less than 5 km from the planned limits of any existing open-cast mining claim;

8. Any work, installation or secondary or ancillary activity included in the open-cast mining project.

(Modified from Vadillo *et al*, 1988)

Reclamation Related Legislation in India

The prevention of environmental degradation by mining activities is governed by several Federal Acts and Regulations. The Mines & Mineral (Regulations and Development) Act, 1957, is the major act dealing with the regulation of mines and development of mineral resources in India. Its extensive amendment through the enactment of the M & M (R and D) Amendment Act, 1986, contained new provisions which relate to the protection of the environment in the mining industry. Of major importance is the provision in it granting powers to the Federal Government to order closure of a mine or prematurely terminate a mining lease if the mining operations in an area are found to cause damage to the environment or if damage to the environment is foreseen.

Interest in the environment in general, and water supply and quality in particular, was raised by the four year drought which affected the country in the mid 1980's. During the last two years there has been a considerable upsurge in studies on environmental impact assessment and environmental management planning.

Reclamation Legislation - General

In all industralised countries today a variety of laws and regulations require that land reclamation be a concomitant component of mining exploration, development, operations and abandonment. The underlying theme of the laws and regulations governing the reclamation aspects of mining is that land disturbed by mining and associated waste disposal practices is restored to a level of biological productivity, equal to, or greater than that which existed prior to mining and that it is non-polluting.

Reclamation Related Legislation in Spain

Environmental control (including land reclamation) of air, land and water affected by mining is subject to a number of different laws and regulations (Vadillo et al 1988). Relevant legislation was introduced in the province of Catalonia in 1981 and 1983. In Castille and Leon provinces, general legislation governing mining was passed in 1983, while further legislation, specific to the reclamation of land disturbed by coal mining was introduced in 1986.

The other provinces in Spain are governed by laws introduced in 1982 (non-coal minerals) and 1984 (coal). Reclamation plans prepared by an operating company are submitted to appropriate ministries in regional or national government. Technical comment on the reclamation plans is then provided by two institutes, IGME (National Geological and Mining Survey) and ICONA (National Institute for Nature Conservation).

Comprehensive legislation requiring all new or expanding open-cast mines to undertake Environmental Impact Asssessments was enacted in 1988. This legislation was introduced in order to comply with environmental directives within the EEC. The EIA's are subject to public scrutiny. An outline of the mining situations where an EIA must be undertaken are presented in Table 1.

The developments in land reclamation which were characteristic of most westernised countries from the mid 1960's to the early 1980's were almost entirely ignored in Spain. Not until Spain was granted entry into the European Common Market and the consequent need to conform with EEC environmental standards and regulations that "environment" including land reclamation has become a prominent factor in mining and construction developments. Spain, being one of the most highly mineralised parts of Europe and with a mining history extending over many centuries, has a large legacy of mined lands in need of reclamation.

Few people question the fact that the major environmental problem in India today is the restoration of degraded forest lands. Since Independence in 1947, the nation's forest cover has declined from 40 to 23 percent; and only 11 percent is actually truly forested. This represents approximately 33 million hectares, which is continuing to decline by 1,5 million hectares per year.

Some 175 to 200 million hectares of land in India have been been classified as degraded or waste land. The destructive effects of floods and siltation is a consequence of deforestation as evidenced in the heavily populated areas of the Ganges and Brahmaputra river belts. Flood prone areas have increased from 25 million hectares in 1960 to 59 million hectares in 1987. (Rao 1989, Town and Country Planning Organisation 1987).

Legislation, described as "stringent, punitive and comprehensive", was introduced between 1980 and 1987 to rectify the loss of forest lands whether from mining activity or diversion to other non-forest land uses. However, it was not realised, unfortunately, that such enactments would only affect organised sectors of the economy, such as mining and construction. The major factor in forest destruction remains the ever increasing population and its demand for food, fuel and shelter (Thakore 1989).

In South Africa the reclamation of acidic tailings dumps created from gold mining on the Witswaterand is internationally known. Less so, perhaps, are the reclamation activities on other waste dumps and disturbed lands from other mineral and coal mining activities respectively. In general, land reclamation is well integrated with other aspects of environmental control (air and water). During the past three decades, an increasing awareness of the need for improvement in waste management has led to the promulgation of numerous Acts of Parliament and ensuing regulations (Wyk, Wells and Marsden (in press)).

Other areas of emerging interest in land reclamation include, the use of wetlands for attenuation of acid tailings seepage, early treatment of gold tailings dumps so as to allow progressive revegetation to be carried out, shrub and tree plantings and development of waste areas as game refuges to name but a few.

Conclusions

This has been an extremely brief review of land reclamation practices in three countries, each exhibiting widely varied climates and soils, and different economic, social and cultural values. Because of limitations of space, much has been left unsaid as to how each of the above influences land reclamation and associated environmental matters. Perhaps a too simplistic state of affairs has been presented but it is also hoped that some of the flavour of land reclamation in each country has been captured.

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Northern and High Altitude Reclamation

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FACTORS AFFECTING ALPINE GRASS SEED GERMINATION IN RELATION TO THEIR POTENTIAL USE IN RECLAMATION[1]

by

Surya N. Acharya[2]

Abstract. Poa alpina L. seeds germinated best under darkness and 16/8 h cycles of 22/15°C temperature while Agropyron latiglume L. seeds needed a 29/22°C regime and darkness for best germination. Rapid germination in both species occurred within a narrow range of temperature conditions. Light and suboptimal temperature conditions appeared to have an inhibitory effect on seed germination during the initial period of imbibition. Germination inhibition through external factors (secondary dormancy) and the presence of primary dormancy in the nursery-grown seeds may be their adaptation to extremely stressful alpine environments. This and the differences among populations for seed germination in both species are encouraging for the breeding program aiming at selecting genotypes with rapid germination while maintaining adaptation to stressful environments.

Additional Key Words: effect of temperature, light, population, seed germination, alpine grasses.

Introduction

The objectives of the native grass breeding program at the Alberta Environmental Centre are to develop cultivars suitable for reclamation of alpine disturbances and rangeland improvement in the eastern slopes of the Rocky Mountains. Achievement of both objectives depends on proper germination and stand establishment.

Germination and dormancy responses of plants have been the subject of extensive research. However, alpine species have received little attention worldwide, perhaps because of their relative unavailability and minor economic importance. Bliss (1958, 1962), Amen (1964, 1966), Bonde and Foreman (1964), Sayers and Ward (1966) and Clebsch and Billings (1976) studied seed germination of alpine plants mainly for academic interest. In most of these studies, germination of different alpine species was compared using seeds collected from different geographical areas at various times. Therefore, the results of the germination experiments may have been confounded by the effect of the environment under which the seeds were produced (McCullough and Shorpshire 1970; Urbanska and Schutz 1986). The experiments also ignored the presence of genotypic differences in seed germinability among populations within a species.

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Germination capacity of commercially available rangeland grass seed is strongly influenced by temperature (McGinnes 1960; Tadmor et al. 1969; Hsu et al. 1985). Germination of several grasses was better at alternating temperatures than at constant temperatures (Stubbendieck and McCully 1972; McElgunn 1974; Harty and Butler 1975). However, some range grasses demonstrated similar germination under the two conditions (Ellern and Tadmor 1967; Young et al. 1981).

Light is known to have positive, negative or no influence on seed germination in different species and it may interact with temperature, making seed germination sensitive to light at certain temperatures but not at others (Koller et al. 1962; Mayer and Paljakoff-Mayber 1963). For example, Clebsch and Billings (1976) observed dark stimulated germination in Trisetum spicatum populations originating in the Rocky Mountains.

Some alpine and subalpine populations of alpine bluegrass collected from the Alberta Rocky Mountains exhibited variability in and adaptation to low temperature regimes for seed production (Hermesh and Acharya 1987). Clebsch and Billings (1976) reported that T. spicatum seeds from lower latitudes reached maximum germination at higher temperatures than those from higher latitudes. However, the data presented for Alberta material only show differences among seeds which originated in different parts of the Rocky Mountains.

In many alpine and subalpine habitats moisture conditions favorable for seed germination may only be present for periods of a few weeks (Sayers and Ward 1966). Therefore, genotypes capable of rapid seed germination might establish better than genotypes with slower rates.

The objectives of the present experiments on alpine and subalpine Poa alpina (alpine bluegrass) and Agropyron latiglume (broad glumed wheatgrass) populations were to determine (1) the effect of temperature and light, and their interaction, on seed germination while seeking the optimal conditions for this process, (2) the presence of variation among populations within a species for germinability, and (3) the presence of seed dormancy.

Materials and Methods

In the summers of 1984 and 1985, collections of P. alpina and A. latiglume were made from 318 sites scattered over the Rocky Mountains of Alberta. Ten tussocks of each grass were collected at random from each site (5 m in radius). For the present experiments, tussocks from five sites were used (Table 1). Sites 18 and 19 were in the alpine ecoregion, characterized as the zone above tree line, elevation 2200 m. The major ecological factors limiting plant survival and growth in this region are strong winds, summer coolness and frequent freezing temperatures during the warmest months (Strong and Leggat 1981). Sites 22, 23 and 42 were in the subalpine ecoregion, which is an altitudinal vegetation zone bounded above by the alpine, and below by the montane and aspen parkland ecoregions. It has a cordilleran climate, less severe than the alpine ecoregion, with cold, snowy winters and cool, showery summers (Strong and Leggat 1981). Collected tussocks were transported and nurtured as described earlier (Hermesh and Acharya 1987). The tussocks were then acclimatized outside for two weeks in pots before being transplanted to the Alberta Environmental Centre collection nursery at Vegreville, 100 km east of Edmonton. The nursery grown seeds of four morphologically homogeneous tussocks from each site were bulked to represent the population from that site for the germination experiments.

Mature seeds of *P. alpina* populations Poal 18, Poal 22 and Poal 23 and *A. latiglume* Agla 18, Agla 19 and Agla 42 (Table 1) were harvested during the last two weeks of June 1986. Seed set and development were mostly irregular (wild type), necessitating selection of well developed and undamaged seeds for experimentation.

Twenty five surface sterilized seeds from each population, constituting a replication, were placed into 9 cm petri dishes on two sheets of Whatman No. 40 filter paper. Starting on October 7, 1986, distilled water was added as necessary during incubation at 36/36, 36/29, 29/22, 22/22, 22/15, 15/8, 8/8 and 8/1°C day/night temperature regimes in germination chambers. Within each temperature regime the light treatment was provided by a 16 h photoperiod with an intensity of about $15 \mu EM^{-2}S^{-1}$. The dark treatment was provided by covering the petri dishes with disposable aluminum-foil casserole pans. Within a germination chamber, temperature conditions varied considerably. To reduce the effect of such variability the light and dark treated

Table 1. Origin, summer[†] temperature conditions and population designations of the tested tussocks.

			Mean daily summer				GDD[‡] above 0°C	Population designation	
Site	Location	Elev. (m)	Max. temp.	Min. temp.	% Chance of frost	Extreme low temp.		Poal[§]	Agla
18	Sugar Loaf Mtn.	2510	13.4	3.2	80	-13.3	805	-	Agla 18
19	Sugar Loaf Mtn.	2500	13.4	3.2	80	-13.3	805	Poal 19	Agla 18
42	Hail Stone Butte	2150	14.9	4.2	33	- 9.4	904	-	Agla 42
22	Sugar Loaf Mtn.	2040	15.2	5.5	33	- 6.7	973	Poal 22	-
23	Sugar Loaf Mtn.	1550	17.2	6.4	33	- 6.0	1092	Poal 23	-

[†] June-August data based on climatic normals (Canada, Atmospheric Environment Service, 1982);
[‡] GDD = Growing degree days.
[§] Poal = *Poa alpina*; Agla = *Agropyron latiglume*.

dishes of every population were randomized in a tray and the trays representing four replications were randomized within a chamber constituting a temperature regime. Relative humidity was maintained at about 90%. The dishes were examined under green light, to avoid light exposure of dark treated seeds, every Monday-Wednesday-Friday till the end of the sixth week. Seedlings with distinct radicles were considered germinated and were removed from the petri dishes. At the end of six weeks the nongerminated seeds were treated with 100 ppm gibberelic acid and incubated under darkness and 16/8 h cycles of 22/15°C for twelve more weeks to test the viability. Using the same method and seed material, another germination test was conducted in the fall of 1987. Cumulative germination percentages at the end of every week were arcsin transformed, before analysis of variance (ANOVA) was carried out using the model in Table 2. Germination index (GI) indicating relative rate of germination for different treatments was calculated by using the formula

$$\text{GI} = \frac{\Sigma\,(\text{No. of seeds germinated x No. of days})}{\text{total number of seeds germinated}}$$

A protected 5% least significant difference (LSD) was used for comparison of cumulative germination and germination index after 7, 14, 21, 28 and 42 days of imbibition.

Results

P. alpina and A. latiglume seeds did not germinate at the 36/36 temperature regime during 42 days of imbibition. However, removal of these seeds to a dark 22/15 regime

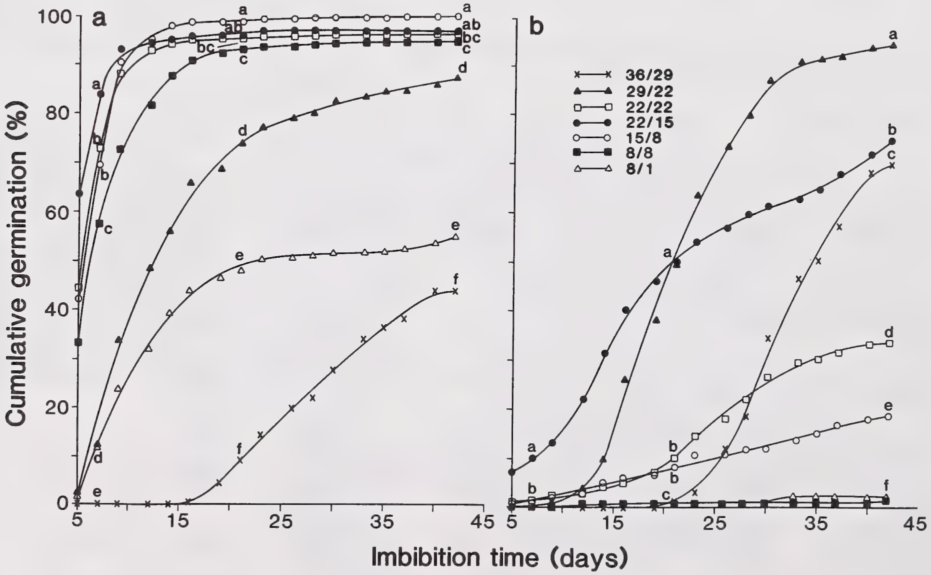

Figure 1. Influence of temperature on cumulative germination of (a) P. alpina, (b) A. latiglume. Points indicated by different letters at 7, 21 and 42 days of imbibition are significantly different (LSD, 5%).

resulted in 25% germination within 90 days. For *P. alpina* maximum germination occurred within 30 days of imbibition in all but 36/29, 29/22, and 8/1 temperature regimes (Figure 1a). At these regimes germination was occurring even at the end of the 6th week. At the 36/29 regime, germination started after two weeks of imbibition and increased steadily to reach 45% by the 40th day. The 22/15 temperature regime produced significantly higher total germination than the other regimes during the first week of imbibition. After that germination was similar for the 22/15 and 15/8 temperature regimes where 90% germination occurred within the initial 10 days of imbibition. Maximum total germination (95%) in *A. latiglume* was observed at the 29/22 temperature regime after 42 days of imbibition (Figure 1b). However, for the initial 19 days the 22/15 regime produced significantly greater total germination than the 29/22 regime. The only other regime where germination for this species crossed 60% at the end of six weeks was 36/29. In the 36/29 regime there was no germination till the 19th day. GI calculated over the six-week period indicated a highly significant temperature effect on both the grass species (Table 2).

Significantly higher cumulative germination occurred under darkness than under the 16 h photoperiod during the first 21 and 14 days of imbibition in *P. alpina* and *A. latiglume*, respectively (Figure 2). In the latter case the effect of light reversed after the 30th day of imbibition. Light had significant effect on GI during the initial two weeks for *P. alpina* and during the first two weeks and the 6th week of imbibition for *A. latiglume* (Table 2).

Table 2. Sources of variation, degrees of freedom and probability of obtaining as large an F value for germination index calculated after 14, 28, and 42 days of imbibition for each species.

		Poal			Agla		
Source	df	GI14	GI28	GI42	GI14	GI28	GI42
Replications (years)	1	NS	NS	NS	NS	NS	NS
Temperature	7	*	***	**	*	**	**
Error (a)	7						
Light	1	*	NS	NS	*	NS	*
Temperature x light	7	*	NS	NS	NS	NS	NS
Error (b)	8						
Population	2	*	*	**	NS	**	**
Temperature x population	14	NS	***	***	*	***	***
Light x population	2	NS	NS	NS	NS	NS	NS
Temperature x light x population	14	*	NS	NS	NS	NS	**
Error (c)	32						
Sampling Error	288						
Total	383						

***P=0.001; *P=0.05; NS=Not significant.

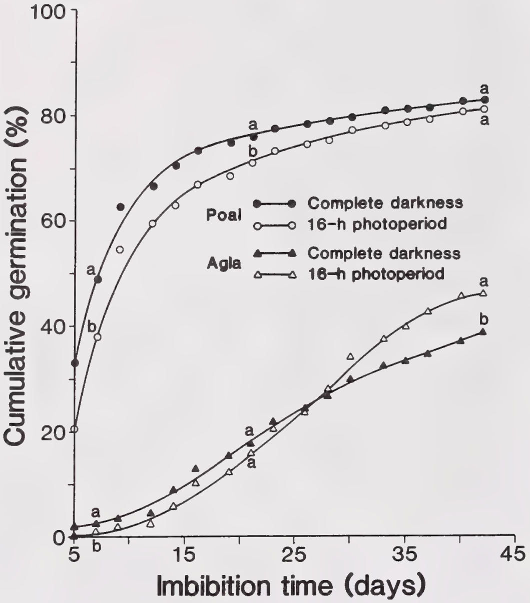

Figure 2. Influence of light on cumulative germination of P. alpina and A. latiglume. Points indicated by different letters at 7, 21 and 42 days of imbibition are significantly different (ANOVA, P = 0.05).

Cumulative germination of Poal 22 was significantly greater than the other two P. alpina populations (Poal 18 and Poal 23) initially (Figure 3). After three weeks of imbibition the three populations had similar germination. By day 42 the total germination of Poal 23 was significantly greater than Poal 18. Seeds of Agla 18 germinated significantly better than the Agla 19 and Agla 42 after 21 days of imbibition (Fig. 3). By day 30 the three populations differed significantly from each other. A significant effect of population on GI occurred during all six weeks in P. alpina and last four weeks in A. latiglume (Table 2). Significant population x temperature, population x temperature x light interactions occurred in both grass species GI (Table 2).

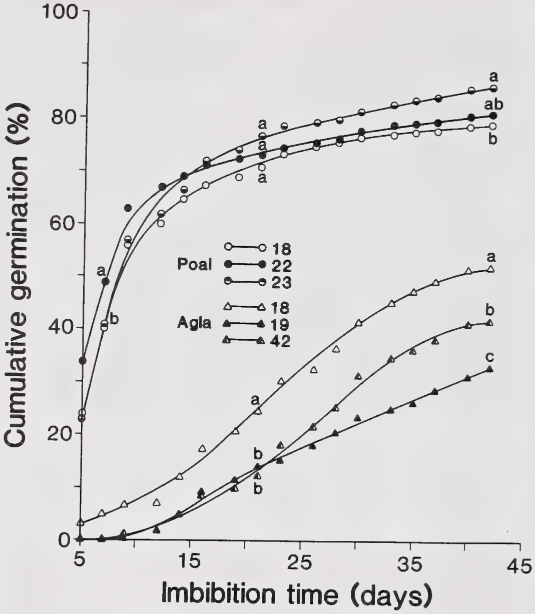

Figure 3. Influence of population on cumulative germination of P. alpina and A. latiglume. Points indicated by different letters at 7, 21 and 42 days of imbibition are significantly different (LSD, 5%).

Discussion

Poa alpina and *Agropyron latiglume* seed germination was strongly influenced by temperature and the optimum temperatures were 22/15 and 29/22°C, respectively. Marked effects of temperature on forage grass seed germination were earlier observed by McGinnes (1960), Tadmore *et al*. (1969); and Hsu *et al*. (1985). No germination at the 36/36 regime and significantly lower total and rate of germination at the 36/29 regime than 29/22 regime after 42 days indicates a threshold germination temperature lower than 36°C for these grasses. This is in contrast to the findings of Hsu *et al*. (1985) where some warm season forage grasses germinated better at 36°C than at lower temperatures. Low threshold germination temperature may be associated with their adaptation to colder high elevation environments. This suggests that poor emergence may result from seeding these into dark mineral oberburden during midsummer when mid day temperatures can reach above 40°C.

The optimum temperatures of 22/15 and 29/22 for *P. alpina* and *A. latiglume* germination, respectively, are similar to those that give the best seed germination in many cultivated species at low elevations (Sayers and Ward 1966; Hsu *et al*. 1985). This indicates suitability of these nursery-grown seeds for low elevation propagation.

For *P. alpina* seed germination, the effect of the constant temperature regime (22/22) was similar to the fluctuating temperature regime (22/15). This was also observed in range grasses like bluebunch and beardless wheatgrass (Ellern and Tadmor 1967; Young *et al*. 1981). However, fluctuating temperatures (22/15) had a marked positive effect over constant temperatures (22/22) on *A. latiglume* seed germination as was observed in some warm and cool season grasses (Stubbendieck and McCully 1972; McElgunn 1974; Harty and Butler 1975; and Williams 1983). In general, *P. alpina* seeds germinated well over a wider range of temperatures than *A. latiglume* seeds.

Light had a significant effect on alpine grass seed germination. *Poa alpina* seeds germinated better in darkness than under 16 h photoperiod unlike *P. annua*, *P. trivialis* and *Deschampsia caespitosa* where light has a positive effect (Williams 1983). The seeds of *A. latiglume* germinated more and faster during early imbibition in darkness. However, final germination under the 16 h photoperiod exceeded germination in darkness. Such an effect of light and darkness was also observed in alpine *T. spicatum* by Sayers and Ward (1966). Early loss of seed dormancy under darkness caused by burial may be an adaptation of plants growing in fluctuating alpine conditions. Rapid loss of dormancy in seeds that imbibe water while on the surface receiving light, particularly at suboptimal temperatures, may lead to early death of seedlings in the unstable alpine environment. To avoid such consequences seeds exposed to light probably after-ripen slowly allowing germination only after a prolonged exposure to higher temperatures.

In *P. alpina* and *A. latiglume* the temperature regimes at which dark and light treatments had the biggest difference in seed germination were 8/8 and 22/22, respectively. The light and dark treatments had the least influence on germination at optimum temperature regimes for the two species. However, for rapid initial germination the recommendation is to use optimum temperature conditions for the species and complete darkness during imbibition. Faster germination in darkness also suggests that seed drilling will be more successful than broadcasting while establishing field plots.

Gradual germination of mature seeds after two months of harvest under optimal germination conditions indicates the presence of primary seed dormancy in the two test species. Faster germination of *P. alpina* seeds, 15 days to 90%, than the *A. latiglume*, 35 days to 90%, demonstrates a shorter after-ripening period for the former. The observed slow resumption of seed germination, 25% in 90 days, after moving 36/36 regime seeds to optimal conditons indicates the presence of induced secondary dormancy. Amen (1966) observed seed dormancy in other alpine species and concluded that this adaptive mechanism often confers a selective advantage in distribution and abundance of some alpine species.

High total and rates of germination observed in our nursery-grown seeds of alpine grasses, as was observed by Urbanska and Schutz (1986) in other alpine species, suggest the suitability of these grasses for agricultural situations. On the other hand, the ability of these nursery-grown seeds to acquire dormancy under unfavourable conditions indicates the preservation of their adaptation to alpine environments.

Populations originating in close proximity such as Agla 18 and Agla 19; Poal 22 and Poal 23 germinated differently in both species. Since the populations tested in these experiments were grown in one nursery, harvested during the same week after maturity and seeds were handled the same way, the effect could not have been confounded with external factors. The observation may partly be due to vegetative mode of reproduction, including production of apomictic seeds, in situ and the presence of physical barriers for germplasm exchange in mountainous regions. The self pollinating nature of _A. latiglume_ may have enhanced the process of genotypic divergence among plant populations living in close proximity. The presence of variability for total and rate of germination among native populations suggests the possibility of genetic advance through selection for these traits. Significant population x temperature, and population x temperature x light interactions for both species suggests that a mechanical mixture of different types rather than a single homogeneous line will be required for successful reclamation of alpine and subalpine disturbances.

In conclusion, these experiments demonstrate the strong influence of environment on seed germination. They also indicate the presence of primary and secondary dormancy in the seeds of the two alpine grasses. These dormancies may be adaptive, allowing population survival under extreme environments, and therefore it will be necessary to take steps to preserve these traits in the breeding program. The variability for seed germination in alpine populations growing in close proximity is encouraging from the breeding standpoint.

Acknowledgements

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IMPACT OF CLIMATE ON RECLAMATION SUCCESS IN THE FOOTHILLS/MOUNTAINS REGION OF ALBERTA, CANADA[1]

by

T.M. Macyk, Z.W. Widtman[2] and V. Betts[3]

Abstract. The Alberta Research Council has conducted a reclamation research program near Grande Cache, Alberta in conjunction with the surface mining operations of Smoky River Coal Limited since 1972. Use of appropriate materials handling techniques and selection of suitable plant species combined with good management practices has resulted in the establishment of diverse plant communities that allow for different land use options. Climate was recognized as the most limiting factor to reclamation success in the region. Precipitation records were maintained on a growing season basis since the inception of the program. More recently, continuous monitoring equipment was installed to measure precipitation, air and soil temperature, wind speed and direction and relative humidity on a continuous basis. Frost-free period has ranged from 45 days to 112 days during the last five years. Soil temperatures at the 1 cm depth were found to exceed 46°C for several hours on consecutive days in areas characterized by a grass and legume cover. Measurement of the distribution and intensity of precipitation events indicates that the distribution of moisture can be somewhat less than effective for good plant establishment and growth. Prevailing winds are from the west and south. The data collected in the monitoring program are used to develop and refine operational reclamation procedures used in the area.

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Introduction

The Alberta Research Council has conducted a reclamation research program near Grande Cache, Alberta in conjunction with the surface mining operations of Smoky River Coal Limited since 1972. The development of effective materials handling techniques and selection of appropriate plant species combined with good management practices has resulted in the establishment of diverse plant communities that allow for different land use options (Macyk and Widtman 1987; Macyk 1985). Emphasis on materials handling techniques and revegetation concerns did not allow for any quantitative measurement of climate parameters in the early stages of the program. During the course of the study climate was recognized as the most limiting factor to reclamation success in the region. This paper provides a summary of the climatic parameters monitored, the results obtained and the relationship of these parameters to reclamation success.

Setting

The operations of Smoky River Coal Limited are located approximately 150 km north of Jasper in the Rocky Mountain Foothills. The three major surface mining operations are the No. 8, No. 9 and No. 12 Mine areas located adjacent to the Smoky River and Sheep Creek respectively. Elevations range from 1600 to 1800 m and the topography is steeply sloping.

Materials and Methods

Beginning in 1973 precipitation was measured each year during the period May 1 to September 30. This period varied by a few days annually on the basis of the time that researchers were on site. As the significance of the impact of climate on revegetation success became more apparent, and appropriate continuous monitoring equipment became available, a major program to evaluate additional parameters was implemented.

Temperature Measurements

During 1983 a study was initiated to determine the length of growing season and to provide air and soil temperature data. Two different types of monitoring equipment were installed. The Model TA51 Biophenometer (Omnidata International Inc.) is a miniature, battery operated growing degree day computer and chilling hour accumulator. Degree days above 5°C provide an estimate of the growth stage of a plant based on temperature measurements. For each day that the average temperature is one degree above the base temperature of 5°C, one degree day accumulates. One unit was located in the Sheep Creek Valley (elevation 1020 m) and another in the No. 9 Mine area (elevation 1850 m).

At No. 8 Mine, two Campbell Scientific CR21 (Campbell Scientific Inc.) units were installed to monitor soil and air temperature. The CR21 Micrologger is a battery powered microcomputer that can monitor signals from a wide variety of transducers recording a broad range of parameters. Air temperature and soil temperature at the 1 cm and 5 cm depths on the crown, north, south, east and west facing-slope positions were measured. Minimum, maximum and average temperatures at two-hour intervals were recorded for each of the locations.

Subsequently, three Model 824 Easylogger units (Omnidata International Inc.) which are 12-channel portable data recorders were installed. With this equipment the air and soil temperatures are measured at three-minute intervals and a minimum, maximum and mean value recorded on an hourly basis.

Precipitation

Precipitation is measured at various locations utilizing the Taylor Clear-Vu rain gauge (Taylor Instrument, Sybron Corporation). Tipping bucket rain gauges have also been installed at three locations in the mine area in conjunction with the Easylogger units.

Other Parameters

Soil moisture is measured by the use of the SM898 Beckman soil moisture block. The LICOR LI-200 SB pyranometer sensor is used to measure solar radiation and the Vaisala HMP IIIA humidity sensor is used to measure relative humidity. Wind speed and direction is measured by the use of the Young Model 05102 wind monitor. All of these instruments are attached to the Easylogger units which measure the respective parameters at three-minute intervals and record minimum, maximum and mean values on an hourly basis.

Results and Discussion

Air Temperature

Detailed air and soil temperature data are available for 1984 to 1988. Experience had indicated that frost and/or snow could occur in any month of the year. The data obtained in 1984 indicated that indeed frost (temperature below 0°C) did occur in each month during the monitoring period. Length of frost-free period and killing frost-free period (temperature below -2°C) for 1984 to 1988 inclusive are illustrated in Figure 1. The length of killing frost-free period exceeded the frost-free period for all years particularly 1984 and 1985.

Another measure of growing season characteristics involves determination of the degree-days that accumulate. Degree-days above 5°C provide an estimate of the growth stage of a plant based on temperature measurements. The data in Table 1 compare the degree-days accumulated at the No. 9 Mine location with an elevation of 1800 m and the Sheep Creek site with an elevation of 1035 m.

The data indicate consistently higher values at the Sheep Creek location which is considerably lower in elevation. To put these data in perspective, the concept of degree-days is used in the definition of climatic zones in Alberta as illustrated in Table 2.

Both the Sheep Creek and No. 9 Mine sites fit the Climate Zone 5 category which represents most of the forested region of Alberta.

Soil Temperature

Soil temperature influences biological, chemical and physical processes in the soil and the growth and overall survival of plants. During the first year of the project, when plot establishment was underway, surface soil temperatures in excess of 50°C were recorded for bare soil materials when air temperature was greater than 25°C. Relatively dark soil materials comprised of soil and coal fines reached temperatures of 55°C and greater. One of the objectives of the monitoring program was to assess the relationship between air temperature, soil temperature and aspect and to apply the information to revegetation techniques and site management.

The data collected were analysed to relate air temperature and soil temperature at the 1 cm and 5 cm depths relative to different aspect, time of year and to some extent color

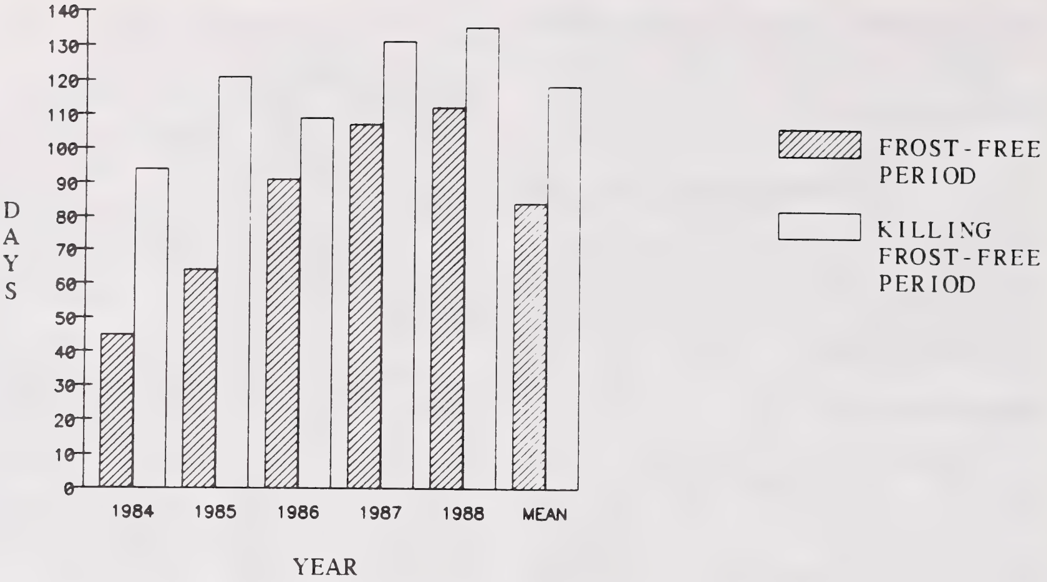

Figure 1. Frost-free and killing frost-free period for 1984 to 1988.

Table 1. Degree-days at the Sheep Creek and No. 9 Mine locations for 1984 to 1988.

	Degree-Days	
Date	Sheep Creek	No. 9 Mine
April 25 to October 3, 1984	919	-
April 10 to October 3, 1985	1023	846
April 15 to October 7, 1986	993	826
April 16 to October 7, 1987	1135	971
April 6 to October 7, 1988	1195	963
Mean	1053	902

Table 2. Degree-days and climate zones in Alberta.

Climate Zone	Degree-Days
1	>2200
2	1900-2200
3	1750-1900
5	<1750

of soil material in locations that had an established vegetation cover. The cover is comprised of a mixture of brome grass (Bromus inermis), creeping red fescue (Festuca spp.), crested wheatgrass (Agropyron spp.) and alfalfa (Medicago sativa). The extent of cover varied relative to aspect with the most dense cover occurring on the north-facing slope and the least dense cover on the south-facing slope and the crown position characterized by a dark soil surface material.

Soil temperatures at 1 cm on the north-facing slope were lowest and the range in temperature between minimum and maximum for a 24-hour period were lowest. Temperatures for the crown and south-facing positions were generally the highest and the range in temperature between minimum and maximum for a 24-hour period was greatest (Figure 2).

Relatively high soil temperatures and the length of time that they are sustained have a bearing on plant growth and mortality, especially tree seedlings.
Surface temperatures of 45 to 50°C can cause stem girdle which occurs when a complete circle of tissue is stricken with bark necrosis in the zone of the root collar causing a collapse of the non-woody stem tissues. Severe girdling of seedlings in the 45 to 50°C range depends on the severity of the soil drought (Day 1963).

Daubenmire (1943) showed that soil surface heating and drought can act interdependently to cause severe seedling mortality. Daubenmire showed that the heat sensitive seedlings of Engelmann spruce (Picea engelmannii) that were grown in moist soil began to suffer injuries at temperatures as low as 45°C when exposed for six hours. Heat injury may become serious for most coniferous species when surface

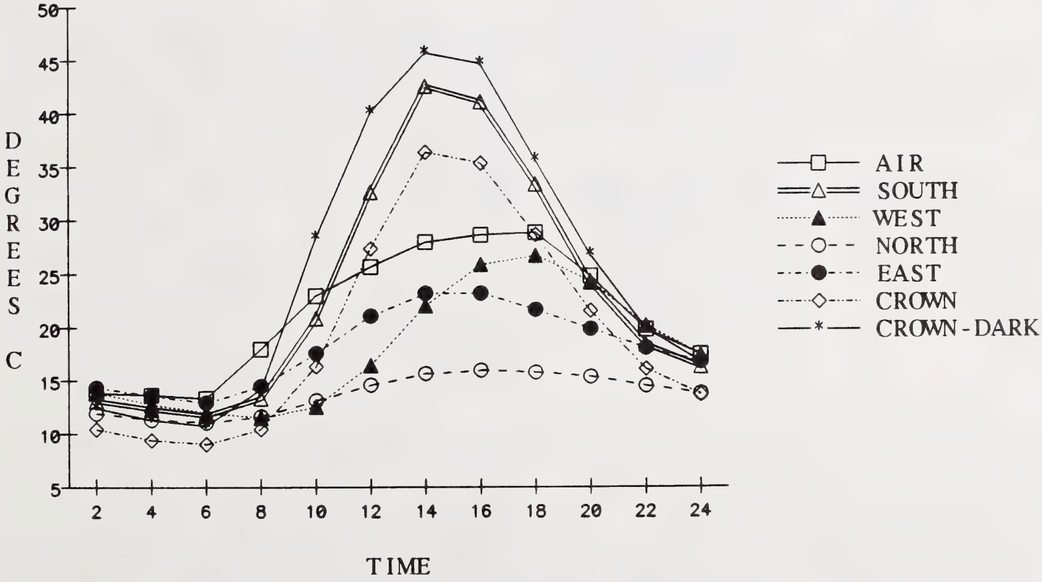

Figure 2. Mean temperature (2 hr interval) at 1 cm depth on different aspects at No. 8 Mine for July 9, 1985.

temperatures in the 50 to 60°C range are reached for periods of a few minutes up to several hours. However, the severity of the injuries in this temperature range is not only dependent on high temperature but also upon limited moisture supply (Day 1963).

The soil temperature data were scrutinized to assess the occurrence of relatively high surface temperatures with surface values being represented by the 1 cm depth and the length of time that these temperatures persisted. For example, mean temperatures in excess of 40°C were reached on three successive days (July 30 to August 1, 1985 inclusive) and these temperatures were sustained for at least six hours on each of the days. During this time temperatures reached maximum values of 52°C with mean values of 46°C being sustained for two to four hours. It is important to note that these high temperatures occurred on the south-facing slope and on the crown position with a less dense vegetation cover and darker soil material than that which occurred on other aspects. These relationships were illustrated in Figure 2.

These data indicate that high surface temperatures are most likely to impact vegetation establishment, growth and survival on the south-facing slopes and at positions where the surface soil is relatively dark.

Additional data were collected to get an indication of the relationship between temperatures that occur at the soil surface and at the 2 and 5 cm depths under a grass/legume cover and under a grass/legume cover with alder.

The temperatures that occurred under cover including a grass/legume and alder cover were considerably lower than those under a grass/legume cover. This is one of the major reasons why tree seedlings more readily become established and thrive in areas with an existing grass/legume and shrub cover.

Precipitation

Precipitation for the May 1 to September 30 period or the approximate growing season was monitored throughout the program and the results presented in Figure 3.

The precipitation total for a growing season is important, however, distribution of rainfall throughout the season is critical for effective plant establishment and growth. Tipping bucket rain gauges were installed to assess the distribution and intensity of rainfall events at different locations.

The data presented in Table 3 provide a rainfall summary for three sites at each of the No. 8 and No. 9 Mines in 1987. The data indicate that the total values for the period were relatively uniform however, large differences did occur over short distances for individual days or rainfall events. For example, for the July 6 to July 8 interval the sites at No. 8 Mine which are about 400 m apart had totals ranging from 8.0 to 17.0 mm. Similar variability was noted for the sites at No. 9 Mine.

Depending upon specific location, 58 to 36% of the total rainfall in 1987 occurred between July 8 and August 18 with the bulk of this occurring in August. It is important to note that only 50 to 60 mm occurred

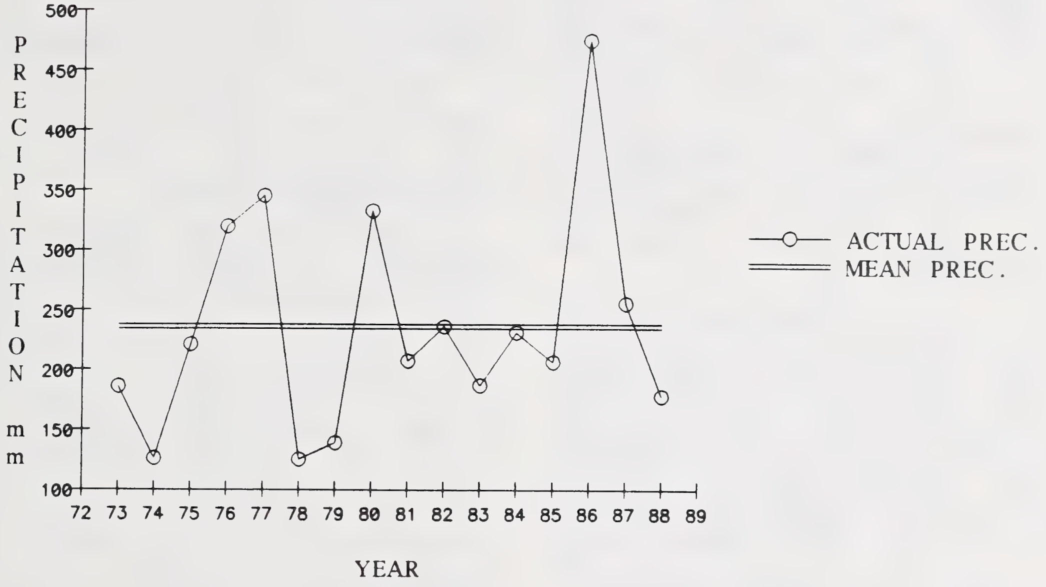

Figure 3. Precipitation for growing season at No. 8 Mine for 1973 to 1988.

Table 3. Precipitation data (mm) summary for 1987.

	Location					
	No. 8 Mine			No. 9 Mine		
Date	I	II	III	A	B	C
April 30 to June 1	30.6	20.2	22.1	18.3	19.1	20.2
June 1 to July 6	28.7	35.8	38.0	31.7	32.0	41.6
July 6 to July 8	12.6	17.0	8.0	9.8	8.0	3.0
July 8 to July 18	155.0	143.2	140.6	149.3	151.0	145.3
August 18 to September 21	27.6	34.3	30.0	25.8	19.0	24.0
September 21 to October 7	14.0	14.7	15.4	14.2	11.0	17.7
Total	268.5	265.2	254.1	249.1	240.1	251.8

between April 30 and July 6 which suggests that a severe moisture deficit occurred during that time. This deficit was evident in the relatively poor growth of vegetation and lack of germination of newly seeded areas in the spring of 1987. This phenomenon of relatively low rainfall values in the spring and fall has occurred for several years in which records have been maintained.

Very often the distribution of the rainfall has been somewhat less than effective for good plant establishment and growth, and the intensity of precipitation was such that a major portion of the water was lost through runoff. Table 4 provides an indication of the distribution and intensity of rainfall that occurred in the months of June, July and August in 1988.

The data indicate that intensity of rainfall was quite variable. For example, in June, 4 mm of rain was recorded in 24-, 42- and 48-minute periods and on one day in 21 hours and 51 minutes. Infiltration and runoff would vary with each of these events.

Wind Direction and Speed

Wind is a common phenomenon in the area. During the initial establishment phase of the study it seemed that the wind blew constantly and on many days disrupted normal field activities. Observations during the course of the study provided some evidence of the effect of wind on revegetation success. Strong winds during the winter months tended to blow snow cover off the mined and revegetated areas and wind chill levels had a devastating effect on newly planted or established tree seedlings.

Table 4. Rainfall data for June to August, 1988 at No. 8 Mine.

Date	Rainfall (mm)	Time Elapsed
June 4	1	-
June 5	5	14 hr 29 min
June 6	18	16 hr 48 min
June 7	4	21 hr 51 min
June 8	2	26 min
June 10	4	48 min
June 11	8	6 hr 53 min
June 13	4	42 min
June 20	1	-
June 23	1	-
June 26	4	24 min
June 27	1	-
June 28	14	4 hr 31 min
June 29	19	17 hr 25 min
Total	88	
July 2	6	25 min
July 4	5	20 hr
July 5	2	14 hr 29 min
July 6	2	28 min
July 11	14	4 hr 57 min
July 29	1	-
July 31	5	6 hr 11 min
Total	25	
August 1	11	19 hr
August 4	3	3 hr 44 min
August 15	4	6 hr 14 min
August 16	9	17 hr 20 min
August 18	4	8 hr 21 min
August 20	1	-
August 29	6	1 hr 5 min
Total	38	

Wind is often considered to have a negative effect on vegetation growth especially in terms of its desiccating effect both on the plant itself and the soil medium.

During the month of July, 1988 the average wind velocity was 26.4 km/hr. To get an indication of the extremes that occurred maximum velocities above 70 km/hr were investigated. The data indicated that maximum velocities in excess 70 km/hr occurred on 11 days and the maximum velocity recorded was 89 km/hr. In August, 1988 a total of eight days had maximums in excess of 70 km/hr. The highest velocity measured was 128 km/hr.

Hourly wind data for the months of January and February, 1988 were assessed in detail to provide an indication of the potential impact of winds during winter months. In January there were 48 hours with wind in excess of 70 km/hr and 9 hours when wind velocities exceeded 90 km/hr. In February there were 98 hours with wind exceeding 70 km/hr and 32 hours when wind velocities exceeded 90 km/hr.

Daily wind velocity means were calculated from hourly data for six consecutive days in February, 1988 and are presented in Table 5.

In the No. 8 and No. 9 Mines a major portion of the reconstructed area is characterized by south and west-facing slopes. Knowledge of the direction of the prevailing winds is a useful parameter in selecting vegetation species and designing material replacement options. Table 6 provides an indication of wind direction for July, August and September, 1988.

Westerly winds were dominant during the period described in Table 6.

Table 5. Mean daily wind velocities and air temperature values for February 16 to 21, 1988

	Wind Velocity (km/hr)			
Date	Average	Minimum	Maximum	Temperature ($^{\circ}$C)
February 16	51.5	32.4	78.2	-3.2
February 17	53.9	38.7	78.4	-0.5
February 18	50.8	32.5	71.5	1.6
February 19	52.2	32.5	73.0	-2.7
February 20	60.4	41.0	89.9	-2.4
February 21	68.1	49.2	77.5	-4.3

Table 6. Wind direction measured at No. 9 Mine in 1988.

	Hours of Wind			
Month	North	South	East	West
July	12	221	131	372
August	0	205	195	312
September	0	178	174	316

Conclusions

The results of the research program indicate that climate impacts revegetation success to a major extent. Extremely high soil temperatures do occur which affect the establishment of vegetation. Precipitation is variable over short distances and distribution during the growing season has resulted in moisture deficits during critical times. Relatively strong winds which prevail during the growing season and winter months affect the establishment, survival and growth of vegetation in the area.

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RECLAMATION OF SEVERELY DISTURBED ALPINE ECOSYSTEMS: NEW PERSPECTIVES[1]

by

Ray W. Brown and Jeanne C. Chambers[2]

Abstract. Early research on revegetation of severely disturbed alpine ecosystems in the Beartooth Mountains of Montana focused on the use of high seeding densities of native colonizer graminoid species and high rates of fertilization. Results showed that these methods tended to competitively exclude the establishment of other species and lifeforms in the community. Initial high applications of nitrogen did not increase long-term nutrient retention capabilities of disturbed sites, and when applications were discontinued, sharp declines resulted in site productivity that further retarded establishment of forbs and other species. In recent years new perspectives of alpine revegetation have been adopted that concentrate on more basic approaches. Research suggests that seed mixtures for harsh disturbances should include species with low nutrient requirements or nitrogen fixing symbionts in addition to high nutrient requiring graminoids, that seeding densities should be reduced, and that moderate applications of balanced macronutrients will likely result in higher species richness and increased rates of succession. Species responses to revegetation treatments appear to be controlled by widely different physiological characteristics and life history traits.

Additional Key Words: revegetation, plant succession, disturbances, amendments, plant species selection,

Introduction

Alpine ecosystems of North America are vitally important watersheds for agricultural, industrial, and metropolitan development. Snow accumulation and water storage at high elevations provide the main sources of summer runoff for streams and rivers. The more gentle slopes and rolling plateaus of alpine regions also provide summer range for both livestock and wildlife, and these unique ecosystems offer stunning panoramas and remote wilderness solitude for recreationists. However, with the advent of modern technology many areas are being disturbed at an accelerated rate by human activities such as recreation, road construction, mineral exploration, mining, and other endeavors.

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[1] Paper presented at the conference Reclamation, A Global Perspective, held in Calgary, Alberta, Canada August 27-31, 1989.

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Severe disturbances of alpine ecosystems threaten their important watershed, wildlife habitat, grazing, and recreational values. Revegetation is essential to minimize the consequences of erosion, loss of water quality, and to reestablish stable native plant communities. However, conventional techniques of revegetation developed for more moderate climatic zones at lower elevations have been largely unsuccessful for disturbed high mountain ecosystems. The rigorous climate of alpine ecosystems, coupled with the impacts of disturbance, dictate the use of revegetation techniques that have been designed for the unique conditions of this life zone. Short, cool growing seasons, strong winds, frequent frosts, and a limited pool of adapted plant species severely complicate revegetation efforts. These constraints are compounded by the effects of disturbance that often results in exposed acidic spoil material that is low in essential plant nutrients or that contains toxic concentrations of heavy metals or other unsuitable constituents. Erosion, acid-water runoff, and sedimentation frequently result in the destruction of offsite plant communities, streams, and aquatic habitats, and the general deterioration of water quality.

Early attempts to revegetate alpine disturbances were frustrated by a lack of knowledge about the complexities of the alpine environment, its interactions with the native flora, and the effects of disturbances. However, numerous promising techniques have been developed in recent years based on the results of basic research on the succession of alpine disturbances and some of the ecological and physiological characteristics of adapted native plant species. Specific techniques including surface shaping and contouring, application and incorporation of fertilizers, lime, and organic matter, methods of seeding and planting, and techniques for applying surface mulches for alpine disturbances have been discussed elsewhere (Brown et al. 1976, 1978, Brown and Johnston 1979, 1980). The purpose here is to discuss some of the primary factors limiting successful revegetation of alpine disturbances and to summarize some of the promising new techniques for revegetation emerging from this research.

Factors Limiting Revegetation

The climatic conditions of alpine ecosystems are often limiting to successful revegetation of disturbances. Generally, these ecosystems have low heat budgets that result in short, cool growing seasons that range from 45 to 90 days in length (Billings 1974). Summer temperatures average about 10°C, frequently falling below 0°C with frost occurring commonly throughout the growing season (Billings and Mooney 1968). Needle ice can uproot seedlings and contribute to surface soil erosion on disturbed sites where soil water status is maintained at or near saturation (Brink et al. 1967). Precipitation in the alpine zone occurs mainly as winter snow, but soil water availability is highly variable with season, location, and topography. For example, snow fields commonly accumulate on the lee sides of ridges while ridgelines may remain nearly snow-free throughout the year due to redistribution by wind. High winds are common in alpine ecosystems and can cause significant soil erosion and be physically and physiologically detrimental to plants. Solar radiation flux densities commonly exceed those at lower elevations.

The type of disturbance imposes various limitations on successful revegetation. Severe disturbances result in the removal of surface soil horizons and expose the underlying geological materials. Less severe disturbances leave the surface soil in place but may result in mixing of the surface and subsurface soil horizons (Chambers et al. 1988). Natural causes of severe disturbances include geomorphological processes such as landslides or avalanches, whereas human causes include such activities as road building and mining. Less severe disturbances result from processes such as freeze-thaw cycles (Johnson and Billings 1962), small mammal burrowing and tunneling (Thorn 1982), and some human recreational activities. The two types of disturbances result in significantly different revegetation environments. Severe disturbances that remove surface organic horizons and leave mineral soils in place are often characterized by lower water and nutrient holding capacities. Disturbance in general can result in the loss of finer soil particles due to wind erosion.

Severe disturbances in alpine ecosystems often leave exposed pyritic materials at the surface that initiate a cycle of sulphide oxidation (Johnston and Brown 1979). This can result in low soil pH and increased availability of potentially toxic metals such as lead, zinc, copper, iron, and aluminum. Plant establishment and growth, and thus natural successional processes, can be severely limited. Runoff from such areas frequently causes mortality to offsite plant communities and seriously degrades water quality and aquatic ecosystems downslope.

Many of the limiting factors associated with disturbances can be ameliorated by careful site preparation techniques. For example, severely disturbed sites should be shaped and contoured to minimize slope angles, sharp ridgelines, and water movement or accumulation. On disturbances where materials such as pyrites are exposed at the surface, the poorest growing media should be covered with soil or spoil using the best available materials on the site. If available, topsoil should be stored and respread over the site prior to revegetation. A complete soil analysis should be performed well before seeding and planting so that limiting physical and chemical properties and nutrient deficiences can be identified (Jurinak 1982, Chambers et al. 1987a). Fertilizer and other required amendments should then be incorporated into the upper 15 to 30 cm of soil or spoil to be available within the rooting zone of germinating seedlings and developing young plants (Brown and Johnston 1979). Lime may be required to improve nutrient availability and to minimize plant absorption of toxic metals and other chemicals where soil pH is lower than about 5.0. Organic matter such as manure or peat moss may be used to improve nutrient and water holding capacities of soil or spoil materials.

A major limitation to successful revegetation of alpine disturbances is a lack of knowledge about the selection and use of adapted plant species. The total flora of alpine ecosystems is relatively small compared with more moderate low elevation life zones, and the pool of adapted species suitable for revegetation is limited. Introduced plant species commonly used for revegetation of lower elevation disturbances are frequently unadapted and unsuccessful when used for revegetation in the alpine zone. Brown and Johnston (1979, 1980) found that such introduced species as Bromus inermis (smooth brome) and Agropyron intermedium (intermediate wheatgrass) were no longer present 4 years after planting on a subalpine-alpine site that had been mined in southwestern Montana. However, native adapted species from the area such as Deschampsia cespitosa (tufted hairgrass) and Poa alpina (alpine bluegrass) increased in density, cover, and biomass production over the same period. The most important criteria used in selecting adapted species for revegetation, including observations of natural succession on disturbed areas, are discussed by Chambers et al. (1984, 1988).

Selection of Adapted Plant Species

One of the most important aspects of successful reclamation is the selection of plant species that are suited to the limiting environmental factors characteristic of a disturbance. Adapted species are those capable of long-term survival and reproduction. One of the most productive field methods of identifying adapted species for revegetation of alpine disturbances is to examine natural successional processes on local old disturbances such as road cuts and fills and gravel pits (Brown and Johnston 1980, Chambers et al. 1984, 1988).

Research results suggest that reclamation success of alpine disturbances may be improved when mixtures of species are planted that represent different life histories and physiological traits. Typically, grasses are the most widely used group of plants in revegetation, yet heavily fertilized swards of high-nutrient adapted grasses often tend to form closed stands that exclude or inhibit the invasion of other species. For example, Brown et al. (1984) found that high seeding rates with a mixture of native grasses and repeated applications of fertilizer on acidic spoil material tended to produce closed plant communities that resisted further successional development and enrichment of species diversity. Their data showed that the use of grasses alone in a revegetation species mixture, together with repeated fertilization for several consecutive years, resulted in no significant changes in species diversity of the revegetation community 8 years following seeding.

Research on plant succession of alpine disturbances suggests that inclusion of different life forms in seeding and planting mixtures, together with appropriate amendments, may increase species and structural diversity of revegetation communities and enhance rates of successional development (Chambers et al. 1988). In addition, use of seed mixtures consisting of species with many different physiological and ecological characteristics improves the chances of stand survival in the event of catastrophic events such as insect infestations, disease, or drought (Brown and Johnston 1980).

In alpine environments many plant species adapted for revegetation of disturbances can be classified according to their frequency of occurrence in different successional stages (Chambers et al. 1984, 1988). Initial colonizers of disturbed sites often exhibit broad ecological amplitudes and are usually widely distributed in geographic area. At low elevations early colonizers tend to include a large complement of annual "weeds" whereas at higher elevations more desirable perennial species predominate. Early colonizers often have large and consistent seed production capabilities, effective seed dispersal mechanisms, high seed longevity, and high rates of growth and development. They may also be able to tolerate high concentrations of heavy metals, low pH, and other adverse disturbance conditions. Late seral species often have slower growth rates, lower seed production and longevity, and lower rates of seed dispersal than early seral species (Chambers et al. 1988). For example, frequent colonizers such as tufted hairgrass typically produce large quantities of small seeds with high seed longevity, high seed dispersal capability, high plant growth rates, and low root to plant biomass ratios (Chambers et al. 1988). In contrast, species typical of late seral communities such as _Geum rossii_ (alpine avens), an alpine forb, produce small quantities of larger sized seeds with relatively short seed longevity, low seed dispersal capability, low growth rates, and high root to plant biomass ratio (Chambers et al. 1988). Also, tufted hairgrass tends to have shallower less extensive root systems and higher nutrient requirements than alpine avens (Chambers et al. 1987_c_). Species adapted to low-nutrient sites, such as alpine avens, can ensure long-term stability on disturbances, but lower rates of production are to be expected (Chambers et al. 1988).

Native alpine species that have successfully been established on disturbed sites from seeds (noted below with an asterisk *), together with others that have favorable characteristics for revegetation include (Brown et al. 1978, 1988, Chambers 1987, 1989_a_, Chambers et al. 1984, 1988):

Grasses and Grasslike Plants:

- *_Agropyron trachycaulum_ (slender wheatgrass)
- *_A. scribneri_ (Scribner wheatgrass)
- *_Carex paysonis_ (Payson sedge)
- *_Deschampsia cespitosa_ (tufted hairgrass)
- *_Phleum alpinum_ (alpine timothy)
- *_Poa alpina_ (alpine bluegrass)
- _P. epilis_ (skyline bluegrass)
- _P. rupicola_ (timberline bluegrass)
- *_Trisetum spicatum_ (spike trisetum)

Forbs:

- *_Achillea millifolium_ (western yarrow)
- _Agoseris glauca_ (pale agoseris)
- _Arenaria obtusiloba_ (alpine sandwort)
- _Artemisia campestris_ (wormwood sagewort)
- *_A. scopulorum_ (alpine sagebrush)
- _Cerastium arvense_ (mouse-ear chickweed)
- _C. beeringianum_ (alpine chickweed)
- *_Geum rossii_ (alpine avens)
- _Lupinus argenteus_ (silvery lupine)
- *_Potentilla diversifolia_ (varileaf cinquefoil)
- _Senecio fremontii_ (Fremont groundsel)
- *_Sibbaldia procumbens_ (prostrate sibbaldia)
- _Smelowskia calycina_ (alpine smelowskia)
- _Solidago multiradiata_ (mountain goldenrod)
- _Trifolium dasyphyllum_ (whiproot clover)
- _T. parryi_ (Parry clover)

Many of the species listed above have broad ecological amplitudes and occur as frequent colonizers on alpine disturbances. Also, many have high reproductive rates and easily collected seeds.

Seed Collection

Unfortunately, the seeds of most native alpine plant species suited for revegetation are not commercially available and must be hand-collected. Seed collection tends to be expensive, but use of locally adapted populations greatly enhances the chances for successful revegetation (Brown et al. 1988).

Seed collection of adapted native species requires a knowledge of the phenology of plant development and the complex interactions with environment. Seed maturity and production are highly variable from year to year, and collection must be opportunistic to take advantage of good seed production years for different species. Chambers (1989b) found significant differences among years and species in seed fill for grasses and viability between grasses and forbs for seeds collected successively between 1983 and 1986 on the Beartooth Plateau in Montana. These differences were attributed to variability in climatic factors such as dates of snowmelt, timing and amount of precipitation, and ambient air and soil temperatures. Large differences among species in seed viability were found, usually with the grasses having lower and more variable seed viability than forbs. Seed longevity of species with life history and physiological traits typical of late seral species was shorter than that of species with traits typical of early colonizer species.

Several years may be required to collect sufficient seed of all species desired for a given revegetation project. Usually, seeds mature on the plant in the late summer or fall and should be collected just prior to natural dispersal. Grass seeds can usually be hand-stripped from the inflorescence directly in the field, although clipping entire culms followed by thrashing has been used successfully. Seeds of most forbs are usually more difficult to collect and clean because seeds are often enclosed within fruiting bodies that must be thrashed and separated following drying. The seeds are normally stored in dry porous containers such as paper or cloth bags and kept in a cool dry environment maintained near 0°C. Storage conditions and seed longevity during storage must be monitored carefully (Chambers 1989b, Chambers et al. 1987a). There is some evidence that seed longevity of high elevation species is improved if stored at -18°C at low moisture content (Billings and Mooney 1968).

Successful revegetation of alpine disturbances is determined to a large extent upon how well techniques emulate natural conditions and modify limiting environments. Fall seed dispersal is typical of alpine plants in the northern hemisphere, indicating that seeds normally lay in the soil over the winter prior to germination and emerge in the spring following snowmelt. Our research indicates that seeding late in the fall mimics natural seed dispersal and enhances seedling establishment on disturbances. Also, fall seeding exposes the seeds to cold dormancy over the winter and permits stratification for those species requiring it (Chambers et al. 1988). Because fall timing of revegetation appears to be critical, both seed collection and seeding and planting may not always be possible in the same year if seed collection and planting times overlap.

Seed Mixtures and Planting Concerns

Seeding rates based on the number of viable seeds per unit area for each species used instead of the more typical method of weight per unit area allows seeding rates to be determined on an individual species seed viability basis. This ensures that potential competition among species will be uniform over the area, provides optimum opportunity for survival of seedlings, and permits success or failure of each species in the mixture to be correctly assessed. The amount of seed applied for each species in a mixture may need to be adjusted for different seed lots collected from different locations and times because seed viability varies widely from year to year (Chambers 1989b).

Seed application rates usually range from about 200 to 500 total viable seeds per m^2, depending on the species used and site conditions (e.g., Chambers 1989a). On particularly harsh sites seeding rates should be adjusted toward the latter figure, whereas more favorable sites should be seeded nearer the former figure. Our experience on alpine disturbances indicates that only about 25 to 80% of the viable seeds applied will germinate and emerge (e.g., Chambers 1987).

Knowledge of seed germination requirements of species is essential to determine seeding methods and other revegetation techniques. Many species have small seeds that cannot emerge from the soil if planted too deeply, whereas species with larger seeds may require deep planting to avoid desiccation during dormancy and seedling development. Also, some species must be planted at or near the soil surface because of a requirement for light during germination (Chambers et al. 1987b, Haggas et al. 1987). Chambers et al. (1987b) found that many alpine forbs require light for germination whereas grasses have less specific requirements. These species should be seeded on the soil surface separately following the planting and incorporation of other seeds on the site (Haggas et al. 1987). Chambers et al. (1987b) found that wet cold stratification during the winter following fall seeding results in fewer days for germination and, consequently, an increased likelihood of seedling establishment the following spring.

In most areas surface mulching with straw or other similar material is essential following seeding (Brown and Johnston 1979, 1980). A surface mulch tends to minimize the redistribution of seed and soil fines by wind, reduces the incidence of frost, and minimizes evaporation at the soil surface. This practice is also important in cases where photoblastic seeds (light requiring) are applied to the soil surface to reduce seed loss due to wind.

Nutrient Requirements for Plant Growth

Use of fertilizer is a common practice in revegetation (Brown and Johnston 1979), yet little is known about the growth responses of native alpine plant species to specific nutrient levels or nutrient requirements (Chambers et al. 1988). Although highly site specific, nitrogen and phosphorus are usually the most limiting nutrients on disturbances, but individual species responses to these nutrients vary widely. The availability of these and other nutrients, and the nutrient retention capacity of a soil are often determined by the severity of the disturbance (Tilman 1982). Chambers et al. (1988) found that tufted hairgrass, a frequent early colonizer on alpine disturbances, responded more to N inputs, and that the typical late successional species, alpine avens, respond more to P. They also show that tufted hairgrass had greater rates of growth at all levels of N and P than does alpine avens. This suggests that tufted hairgrass may have competitive superiority over alpine avens on disturbances and over broad ranges of available N and P.

Factors other than fertility and growth rate may affect the interactions among species in a revegetation mixture. Low growth rates and high root:shoot ratios are important attributes of species adapted to low nutrient environments. Including low nutrient-adapted and low growth rate-adapted species in a seed mixture with those that are high nutrient-adapted and high growth rate-adapted can help ensure long-term stability on nonintensively managed reclaimed disturbances. It may be necessary to use moderate seeding and fertilizer rates and to seed low growth rate species in equal amounts as high growth rate species with such mixtures. High application rates of fertilizer and seeds may favor the high growth rate-adapted and high nutrient-adapted species and result in reduced rates of colonization and succession (Brown et al. 1984).

Research Needs

Although the general techniques developed for revegetation of alpine disturbances appear to be successful, additional research is needed as this life zone comes under increasing pressure from a wide variety of uses. Identification of adapted native species and an understanding of their physiological tolerances and ecological characteristics remain as some of the most urgent needs. We need a better understanding of successional processes on disturbances, including the effects of competition and of nutrient and water relations requirements and interactions. In addition, we need to understand the characteristics and long-term interactions that mycorrhizal and nitrogen-fixing symbionts have with other adapted species on disturbances.

Further research is needed on the long-term effects of various reclamation methods, including soil amendments and the effects they have on species performance and interactions and on soil nutrient retention and cycling. Studies are needed on soil weathering and development and on the dynamics of heavy metals and other toxic materials as they interact with plants. Present methods appear to be inadequate for successfully revegetating the most extreme acidic mine spoils in the alpine zone. Thousands of hectares of abandoned pyritic mine dumps and tailing piles throughout the mountainous West are in the headwaters of watersheds of which increasing demands are being made as metropolitan areas expand. These, together with new mines and other disturbances, are degrading water quality of streams, rivers, and reservoirs throughout the West. Clearly, reclamation research of alpine disturbances needs to be expanded and intensified.

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WHY ARE THE GRASSES GREEN IN ALPINE MEADOWS?[1]

by

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Abstract. Soil samples from the rhizosphere of *Poa alpina* and *Trisetum spicatum* collected on Lookout Mountain, Banff National Park, Alberta contained at least 10 times more bacteria than the soil 3 cm away. The number of bacteria counted on nitrogen free growth media ranged from 5 to 56% of the total heterotrophic count on a minimal (R2A) media. Consistantly more nitrogen fixing bacteria were isolated from the *P. alpina* rhizosphere compared with *T. spicatum* despite their close proximity (<1 m). The microorganisms that readily grew on nitrogen free medium after six successive transfers were identified to be *Xanthobacter flavus*, *X. autotrophicus*, *Azotobacter beijerinckii*, *Azomonas macrocytogenes*, *Flavobacterium multivorum*, *Flavobacterium aquatile* and *Beijerinckia indica*. *P. alpina* seedlings inoculated with nitrogen fixing bacteria *in vitro* remained green and healthy for a much longer time than the uninoculated seedlings when grown in nitrogen free medium. Scanning electron micrographs of the roots of these inoculated seedlings and bulbils planted in Lookout Mountain soil revealed their close association with the bacteria.

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Introduction

Grassy alpine meadows of the Canadian Rocky Mountains present a lush green scenery. On close examination of the grasses, there appears to be no Nitrogen deficiency, although the soil is very low in this element (Macyk, 1974). This poses the question as to how these grasses access a supply of Nitrogen? There is an abundance of literature on biological N_2-fixation in grassy plants and many N_2-fixing microorganisms have been found in the rhizosphere of grasses (Dobereiner, 1961; Dobereiner and Day, 1976; Hashtela et. al., 1983; McClung et. al., 1983; Reinhold et. al., 1988). Among the diazotrophic microorganisms that have been found associated with grass roots, the genus Azospirillum is most the intensively studied (Review in Dobereiner and Perdosa, 1987). The other genera of interest are Beijerinckia (Dobereiner,1961), Campylobacter (McClung and Patriquin, 1980; McClung et. al., 1983), Enterobacter and Klebsiella (Haahtela et. al., 1981; Ladha et. al., 1983), Bacillus (Seldin et. al., 1989), Herbaspirillum (Baldani et. al., 1986), Azotobacter and Derxia (Dobereiner and Pedrosa, 1987).

Some form of plant-bacteria interaction might exist to allow for a mutual relationship or an association. In the absence of gross nodule-like morphological structures and a variability among grass-associated bacteria, the identification of the N_2-fixing systems and of the mechanism involved becomes very difficult. However, considerable progress has been made in establishing such associations for cereals and forage grasses (Boddy and Dobereiner, 1984; Dart, 1986; Dobereiner and Defolli, 1980; Habbell and Gaskins, 1984; Okon, 1983; Reinhold et. al., 1988; Van Berkum and Bohlool, 1980). Dobereiner and Pedrosa (1987) reviewed the evidence of physical association between grass roots and N_2-fixing bacteria. The International Biological Program has helped in understanding the nitrogen cycle in arctic tundra. In cold tundra, bacterial N_2-fixation is believed to be more critical to plant productivity than in any other terrestrial system. Under alpine meadow conditions the grass-bacterial interactions will be similar to that of the tundra ecosystem. However, such interactions have not been extensively studied in the alpine ecosystem. Studies conducted at Niwot Ridge, Colorado (Wojciechowski and Heinbrook, 1984) suggested the strong influence of soil moisture on N_2-fixation. Higher levels of bacterial N_2-fixation were observed in Deschampsia grassy meadows than Xeric kobresia meadow and fellfield. Alpine conditions characterized by low soil temperatures and restricted organic decomposition make biological N_2-fixation significant for the survival of plants in these environments (Alexander et. al., 1978; Alexander, 1974; Wojciechowski and Heinbrook, 1984).

The purpose of this study was to determine the presence of a potential N_2-fixing grass-bacteria association in alpine conditions in the Rocky Mountains of Alberta. This paper will deal with preliminary studies that were conducted with the following objectives; (1) determine presence of a rhizosphere effect in two alpine grasses, (2) identify the most abundant N_2-fixing bacteria in the rhizosphere, and (3) observe grass-bacteria association under natural and artificial environments.

Materials and Methods

Rhizosphere effect

Poa alpina and T. spicatum tussocks with soil clump (5 cm in diameter) were collected from the Lookout Mountain top (2600 m) in two consecutive years. Soil was also sampled from Window Mountain. Soil, shaken free from the outer edges of these clumps, was referred to as non-rhizosphere soil. Approximately 10 g wet weight of this soil was transferred to a milk dilution bottle containing 90 ml dilution buffer (Standard Methods for the Examination of Water and Wastewater, 1985). Similar quantities of rhizosphere soil immediately surrounding the roots in each tussock were collected and treated in a similar manner. Ten fold dilutions of these initial dilutions were made into fresh buffer. Remaining soil was desiccated at 105°C for 16 h and the moisture content determined. This was used to adjust the bacterial count to a soil dry weight basis. Bacterial counts were determined by dispensing 0.1 ml amounts of the appropriate dilution to R2A medium (Difco, Michigan, U.S.A.) and nitrogen free agar medium (NFAM) (Pramer and Smith, 1965). To prepare NFAM, a solution consisting of K_2HPO_4, 1.0 g; $MgSO_4$, 0.5 g; $FeCl_2.H_2O$, 0.1 g; $CaCO_3$, 2.0 g; Noble agar, 15 g and H_2O, 900 ml was prepared and sterilized by autoclave. A second solution consisting of D-glucose, 20g; $Na_2MoO_4.2H_2O$, 2.52 mg; and H_2O, 100 ml was filter sterilized (pore size, 0.22 µm) and added to the first solution after it had cooled to 55°C. The mixed NFAM was then dispensed to sterile Petri plates. Two sets of plates were inoculated in duplicate from each dilution. One set of plates was incubated under aerobic and the other under microaerophilic conditions (Campypack, BBL microbiology system, Becton Dickenson and Company, MD, U.S.A.). After seven days incubation at 20°C bacterial colonies were enumerated.

Bacterial Identification

Major colonies were transferred 5-6 times on NFAM before species identifications were performed by using the computerized identification service at the Alberta Environmental Centre (Coleman, 1981).

Root Bacteria Association

Three experiments were conducted to establish physical association of N_2-fixing bacteria with *P. alpina* and *T. spicatum* roots.

Experiment I: The roots of *P. alpina* and *T. spicatum* tussocks collected from Lookout Mountain were washed carefully and cut into small 1-2 mm pieces. These were then placed into a vial containing fixative (1% paraformaldehyde and 1.5% glutaraldehyde in 0.15 M cacodylate buffer, pH 7.4) under slight vacuum until they sank. The pieces were fixed overnight, washed in 0.12 M cacodylate buffer, pH 7.2 and dehydrated in a graded series of ethanol. While in 100% ethanol, the pieces were transferred to wire baskets making sure to keep them wet. The ethanol was replaced by amyl acetate and the specimens were critical point dried in a SEEVAC critical point drier, mounted on aluminum stubs with silver paint and coated with gold using an Edwards sputter coater. The coated specimens were examined and photographed with a Hitachi S 510 scanning electron microscope (SEM) at the Northern Forestry Centre, Edmonton, Alberta.

Experiment II: Viviparous bulbils (vegetative propagules produced on the spike) of *P. alpina* were planted into rhizosphere soil collected from the Lookout Mountain and greenhouse potting mix (2: LOAM, 1: SAND; 2: PEAT; 1:VERMICULITE). These plants were nurtured in growth cabinets set to a day/night cycle of 15/8°C. After five months, root tips of these plants were prepared and photographed with the SEM as described above.

Experiment III: Seeds of *P. alpina* plants originating from the Lookout Mountain site were surface sterilized (5% sodium hypochlorite for 2 min) and planted into a semisolid (0.25% Noble agar) NFAM contained in test tubes. These test tubes were then placed in a growth cabinet set at 22/15°C day(16 h)/night cycle. After a week of seed germination one third of the test tubes were inoculated with a drop of fresh actively growing cultures (grown in the same liquid medium as used in the experimental plant growth medium) of Azotobacter chroococcum ATCC 9043 and a third with Azospirillum lipoferum ATCC 29707. The rest of the test tubes (not inoculated) were treated as controls. The plants were examined for N-deficiency symptoms for eight weeks. At the end of this period their roots were prepared and photographed using the SEM.

Soil Analysis

Soil samples collected from the field were air dried and ground to 2 mm or less. They were then analyzed for several chemical properties in duplicate using standard methods (McKeague, 1978). Organic matter was determined by oxidation (Walkley and Black, 1934).

Results and Discussion

Rhizosphere Effect

Soil samples taken immediately adjacent to the plant roots (rhizosphere) contained higher numbers of bacteria than soil from 3 cm distance (Table 1). The rhizosphere effect resulted in at least a ten fold increase in bacterial counts for both grass species tested. The proportion of N_2-fixing bacteria in the total populations were similar (69% and 68%) in rhizosphere and non-rhizosphere samples.

Bacterial Identification

During 1986, approximately 30 bacterial isolates obtained from the rhizosphere samples were tested for their ability to grow on NFAM after four successive transfers. Most of the microorganisms were identified as belonging to the genus Xanthobacter.

TABLE 1. Bacterial Counts on Rhizosphere and Non-Rhizosphere soils Collected from Lookout and Window Mountain in Alberta

	CFU/g[a] x10^6				
	R2A[b]		Eugon[c]	NFAM[d]	
Soil Sample	Aerobic	Micro	Micro	Aerobic	Micro
Poa alpina, Lookout Mountain					
Root and Rhizosphere 1986 (n=12)	3,800	ND[e]	830	1,200	ND
Root and Rhizosphere 1987 (n=8)	2,000	1,700	260	470	290
Root and Rhizosphere 1988 (n=8)	540	230	ND	18	16
Non-Rhizosphere soil 1987 (n=4)	110	750	ND	75	56
Non-Rhizosphere soil 1988 (n=8)	19	16	ND	12	12
Poa alpina, Window Mountain					
Root and Rhizosphere 1988 (n=8)	160	63	ND	46	49
Non-Rhizosphere soil 1988 (n=8)	16	9	ND	7	7
Trisetum spicatum, Lookout Mountain					
Root and Rhizosphere 1986 (n=12)	2,500	ND	660	920	ND
Root and Rhizosphere 1987 (n=8)	1,300	630	460	510	450
Non-Rhizosphere soil 1987 (n=4)	250	110	ND	87	77

[a] Colony Forming Units/g dried soil

[b] R2A Growth Medium-Total Heterotrophic Count incubated aerobically and microaerophilically

[c] Eugon Agar incubated microaerophilically

[d] Nitrogen Free Medium incubated aerobically and microaerophilically

[e] Not Determined

Identification of these isolates to species level, plus those identified as Azospirillum and Rhizobium species, was not possible according to the characteristics listed in Bergey's Manual of Systematic Bacteriology. Alpine conditions may have favoured other bacterial species than those typically found associated with lower elevation agricultural soils. Also, alpine soil bacterial populations may well have not yet been classified to species level. Bacterial isolates from P. alpina and T. spicatum rhizospheres were identified as belonging to five and four genera, respectively (Table 2). Among these, well known N_2-fixing bacteria such as

Xanthobacter, *Rhizobium* and *Bacillus* were found to be common to both plant species.

In 1987, about 120 isolates were tested for their ability to grow on NFAM, 39 of them continued to grow under microaerophilic conditions after six successive transfers. Most of the microorganisms were identified as *Xanthobacter*. Bacterial isolates from rhizospheres belonged to four genera (Table 2). The reason(s) for the difference in microbial populations between the two years is not clear. More N_2-fixing bacteria were isolated from, *P. alpina* than from *T. spicatum* rhizosphere (Table 3).

TABLE 2. Bacteria Isolated from *Poa alpina* and *Trisetum spicatum* Rhizospheres in 1986 and 1987 from Nitrogen Free Medium

	Poa alpina
1986	1987
Xanthobacter sp.	*Xanthobacter*
Xanthomonas sp.*	*Xanthobacter flavus*
Azospirillum sp.	*Azotobacter beijerinckii*
Rhizobium sp.	*Azomonas macrocytogenes*
Bacillus sp.*	*Flavobacterium aquatile**
	Trisetum spicatum
1986	1987
Xanthobacter sp.	*Xanthobacter autotrophicus*
Rhizobium sp.	*Flavobacterium multivorum**
Bacillus sp.*	*Beijerinckia indica*
Nocardia sp.*	*Zoogloea ramigera**

* Not known to fix Nitrogen

TABLE 3. Abundance of Nitrogen Fixing Bacteria Isolated from Rhizosphere Samples of the Alpine Plant Species in 1987

Plant Species	Incubation Conditions	# of Isolates	# of N_2 Fixing Bacteria Identified	Genera of N_2 Fixing Bacteria
Poa alpina	Aerobic	16	6	*Xanthobacter* sp. (25%) *Azomonas* sp. (6%) *Azotobacter* sp. (4%)
	Micro*	22	3	*Xanthobacter* sp. (9%) *Azotobacter* sp. (4%)
Trisetum spicatum	Aerobic	34	0	-
	Micro	12	3	*Xanthobacter* sp. (17%) *Beijerinckia* sp. (8%)

* Microaerophilic

Root-Bacteria Association

Root samples of *P. alpina* and *T. spicatum* collected from alpine sites were found to contain bacteria, especially in the cavities and injured areas (Fig. 1a and 1b). Root tips collected from plants grown in the mountain soils carried bacteria, whereas, the control plants (grown in greenhouse potting soil) did not (Fig. 2a and 2b). The vegetative propagule grown in the greenhouse potting soil grew vigorously and showed nitrogen deficiency symptoms. In the mountain soil, on the other hand, the bulbils grew slowly without any N_2-deficiency symptoms (Fig. 3). Seedlings grown in NFAM exhibited N_2-deficiency within two weeks of their germination, whereas, seedlings inoculated with *Azospirillum* or *Azotobacter* species rarely showed N_2-deficiency symptoms. Colonization of the mucilaginous sheath surrounding the roots and root hairs in these cases occurred rapidly and was profuse. The spread of the colonies along the roots could be observed using a light microscope during the first week after inoculation. The inoculated roots were heavily infected with bacteria (Fig. 4 and 5). Under higher magnification these bacteria appeared to be attached to each other and to the root walls by capsular material (Fig. 4b and Fig. 5b). These experiments indicate there is an association between the N_2-fixing bacteria and grass roots and the grasses appear to benefit from such an association. A cold alpine environment, with slow organic matter accumulation and degradation, probably forces the two organisms to cohabit for mutual benefit.

Soil Analysis

Analysis of soil from Lookout Mountain and Window Mountain area revealed low levels of N, P and K (Table 4). The soils were found to be low in salt and slightly alkaline. The alkalinity may explain, in part, the abundance of Gram negative bacteria such as Xanthobacter. The N and Organic Matter (OM) content of the Lookout Mountain soil was about half of that found in the soil collected from Window Mountain. This bias may be due to the fact that the soil from the latter was collected from areas of thick plant cover in order to get the upper range of N, P and K soil levels. Compared to prairie agricultural soil, however, the N content of Window Mountain soil was only 20%. The P and K levels from both alpine soils were also in the range considered extremely deficient for plant growth. Lack of apparent deficiency in the grasses growing in these alpine areas may be due to their inherent low nutrient requirement for growth and reproduction. This lower nitrogen requirement of these plants may be satisfied through their association with N_2-fixing microbial population present in the soil. Inoculation of alpine grass selections with appropriate N_2-fixing bacteria, therefore, may have a positive effect on their establishment and survival, particularly, in areas devoid of the necessary soil microorganisms.

TABLE 4. Mean and Standard Deviation (in parenthesis) of Various Physical and Chemical Parameters of the Alpine Soils*

Sample	pH	EC	Nitrogen(ppm)		P	K	OM
		(mScm^{-1})	NO_3/NO_2	NH_4	(ppm)	(ppm)	(%)
Lookout Mountain (July, 1987)	7.8 (0.1)	0.16 (0.01)	0.5 (0.07)	6.5 (0.78)	9.4 (0.85)	12.1 (0.57)	2.7 (0.14)
Lookout Mountain (Aug, 1987)	7.8 (0.14)	0.12 (0.00)	0.5 (0.07)	6.6 (1.06)	9.5 (0.64)	7.0 (0.00)	2.6 (0.14)
Lookout Mountain (Aug, 1988)	7.8 (0.07)	0.20 (0.00)	0.3 (0.07)	4.6 (0.07)	8.1 (1.06)	4.1 (0.28)	3.2 (0.07)
Phillips Pass (Aug, 1988)	8.0 (0.07)	0.22 (0.00)	5.2 (0.14)	10.8 (0.07)	9.6 (1.13)	16.0 (0.57)	5.7 (0.21)

* Parameters measured were pH, Conductivity(EC), Nitrogen, Phosphorous, Potassium and Organic Matter.

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Figure Legends

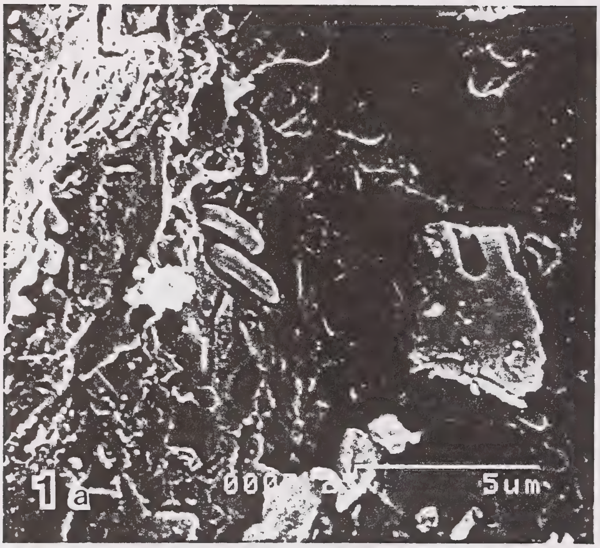
Fig. 1. Bacterial association of (a) *Poa alpina* and (b) *Trisetum spicatum* roots collected from Lookout Mountain.

Fig. 2. (a) Bacterial association of *Poa alpina* roots when grown in Lookout Mountain soil, (b) Absence of bacteria in *P. alpina* roots grown in sterilized greenhouse soil mix.

Fig. 3. Presence and absence of nitrogen deficiency symptoms in plants growing in Lookout Mountain soil and greenhouse soil mix.

Fig. 4. *Poa alpina* roots infected with *Azospirillum sp.* (a) Lower magnification, (b) Higher magnification.

Fig. 5. *Azospirillum sp.* infected *Poa alpina* roots recovered from NFAM. (a) Lower magnification, (b) Higher magnification.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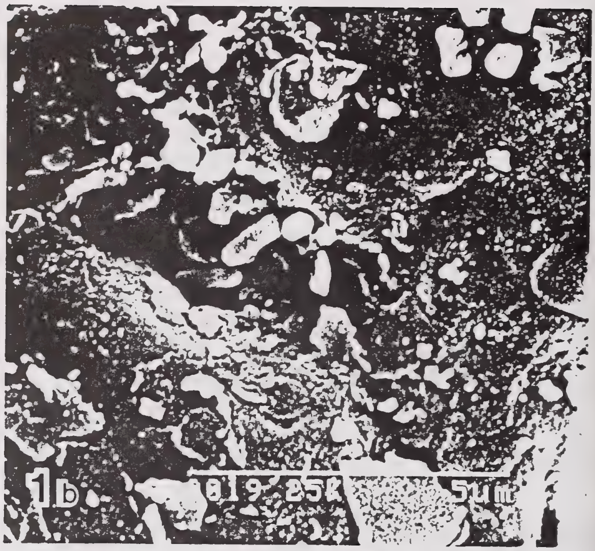
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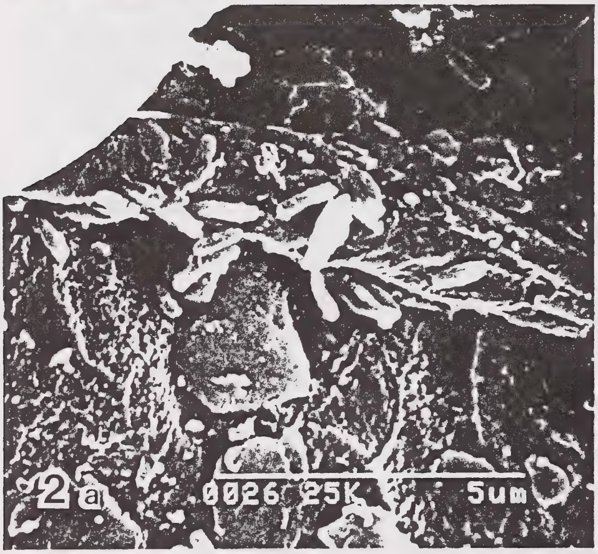
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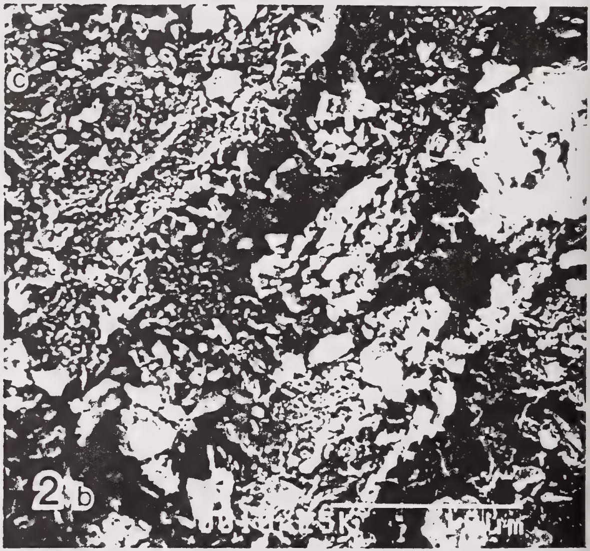
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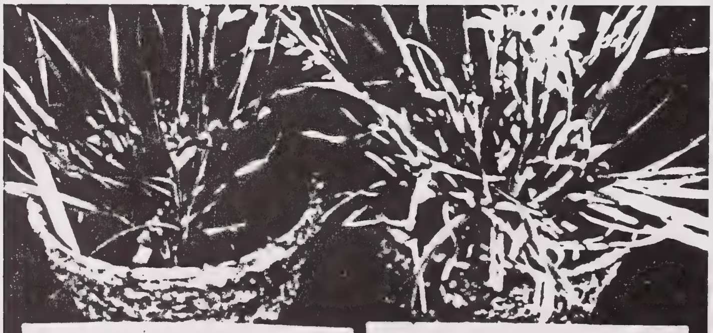
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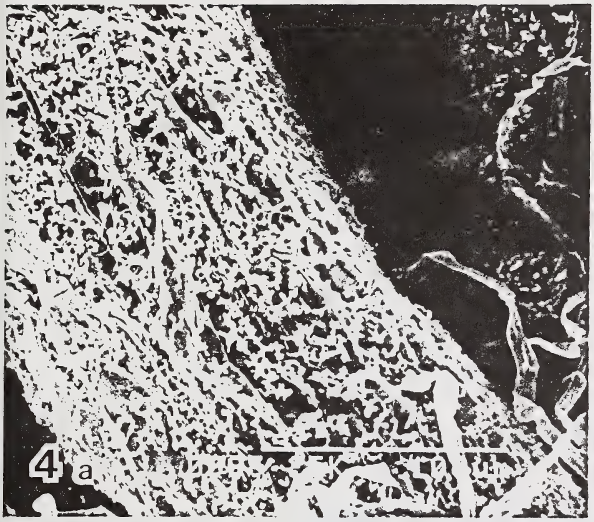
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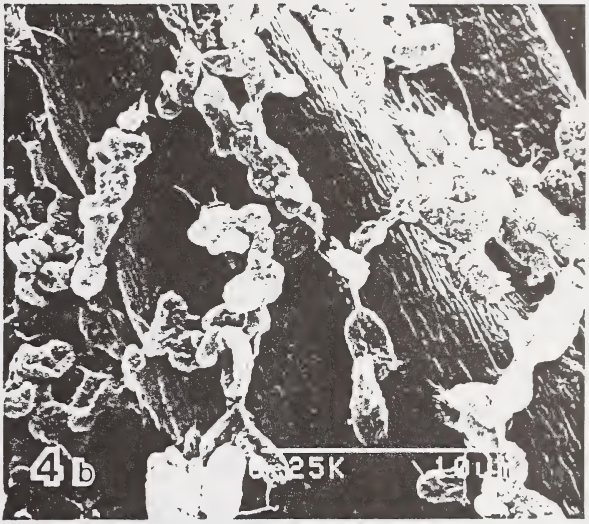
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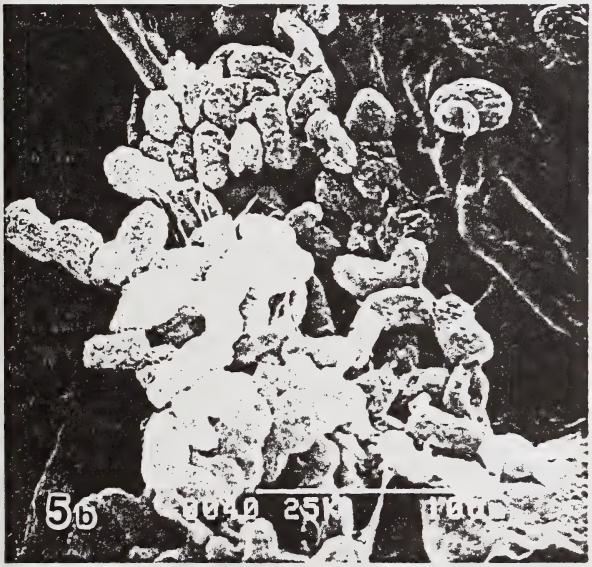
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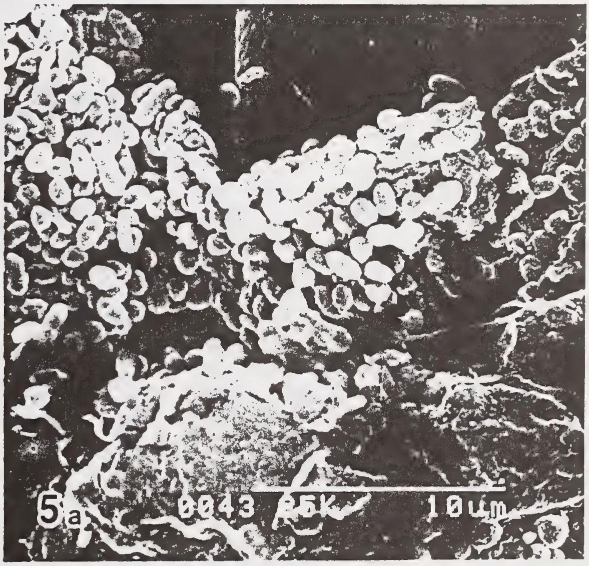
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FIRST YEAR RESULTS OF REVEGETATION TRIALS USING SELECTED NATIVE PLANT SPECIES ON A SIMULATED PIPELINE TRENCH, FORT NORMAN, N.W.T., CANADA[1]

by
Lynn Maslen[2] and G. Peter Kershaw[3]

Abstract. The following revegetation treatments using locally-collected native species and commercially-available native cultivars were seeded with and without fertilizer onto a simulated pipeline trench: local treatments - *Arctagrostis latifolia, Carex membranacea, Arctostaphylos rubra, Betula glandulosa, Empetrum nigrum, Ledum groenlandicum,* and *Vaccinium uliginosum*; commercial treatments - Alyeska polargrass, *Artemesia Tilesii* and *Calamagrostis canadensis*, and Decora seed mix (*Agropyron violaceum, Festuca ovina, Poa alpina, P. glauca*). *Epilobium angustifolium* rhizomes were also planted. *B. glandulosa* and *L. groenlandicum* seeds germinated well but remained as seedlings during the first growing season. *C. membranacea* and the other shrub species did not germinate. Based on above-ground production, fertilized Alyeska polargrass performed better than all other treatments and was the only treatment to respond to fertilizer. The other cultivated and locally-collected herbaceous species all established well and had similar but low above-ground production.

Additional Key Words: biomass, commercial seed, fertilizer, reclamation, revegetation, Subarctic.

Introduction

Depending on site characteristics and programme objectives, the use of native plant species in northern revegetation programmes is now often recommended (Mitchell 1982; McKendrick *et al.* 1984; Elliot *et al.* 1987; Johnson 1987), but seldom implemented, despite the fact that several plant species native to the North have been identified as suitable candidates for revegetation (Chapin and Chapin 1980; Miller *et al.* 1983; Cargill and Chapin 1987; Kershaw and Kershaw 1987; Mitchell 1987; Vaartnou 1988). Reasons cited for this usually include the lack of commercially available seed and slow rates of establishment. Attention is now focusing on producing a readily-available stock of native seeds for commercial purposes and several cultivars of northern species are now available (Mitchell 1982; Miller *et al.* 1983; Wright 1989). However, most cultivation programmes are still in an early stage and a need for additional field testing of cultivars remains. As well, few field tests have been conducted to assess performance of candidate species. In order for native species to gain acceptance with practitioners they must be tested under controlled field conditions.

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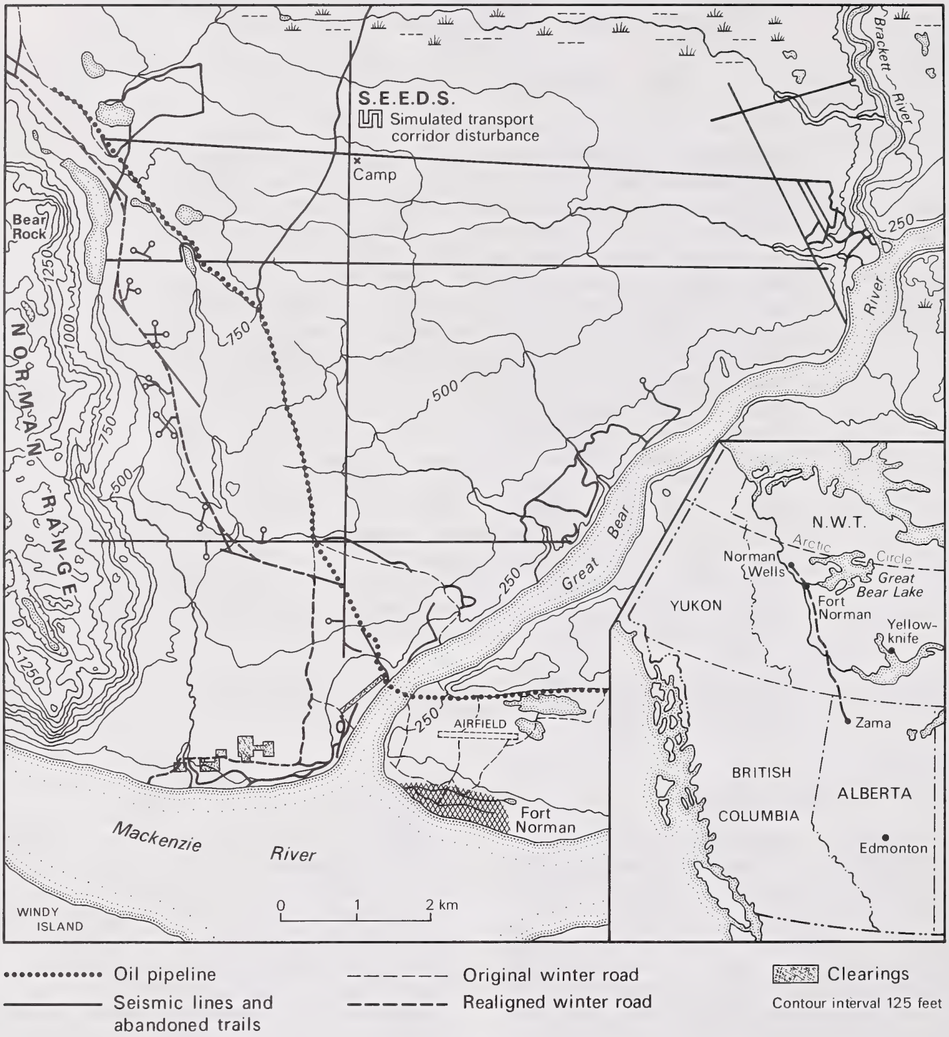

Figure 1: Location of the simulated transport corridor, SEEDS, Fort Norman, NWT.

In permafrost-affected terrain the amount of dry matter produced is important as it can contribute to the insulation of the soil surfacelayers (Viereck 1973 and 1982) and thus reduce soil heat flux during the thaw season (Rouse 1982). It is particularly important to quickly accumulate organic matter because of its influence on soil heat flux but also because of its significance for soil characteristics such as fertility, erosive potential and moisture content. Development-related surface disturbances in Subarctic terrain often result in either the compaction or removal of surface organic layers (Kershaw 1983). It is therefore important to replace these surface layers as quickly as possible following their modification. Plants exhibiting high rates of biomass concentration are therefore most desirable.

In addition, vegetation on disturbances will be utilized by resident wildlife species for cover and food. In order to minimize impacts on wildlife, reclamation programmes must consider the time required to establish cover and the amount and quality of forage produced (Densmore *et al.* 1987).

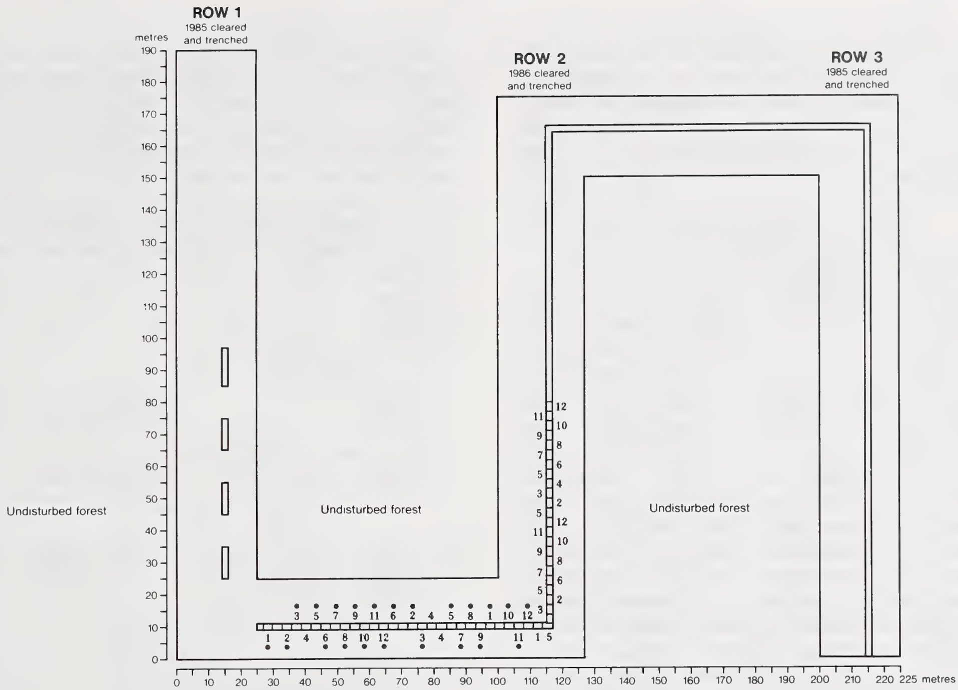

Figure 2: Revegetation test treatments on ROW 2 and South Link, SEEDS, Fort Norman, NWT. (1) *Artostaphylos rubra* seed, (2) *Arctagrostis latifolia* [Alyeska polargrass] seed, (3) *Epilobium angustifolium* rhizomes, (4) Untreated [control], (5) *Empetrum nigrum* seed, (6) *Artemisia Tilesii* and *Calamagrostis canadensis* seed, (7) *Carex membranacea* seed, (8) *Betula glandulosa* seed, (9) Decora grass seed mix, (10) *Vaccinium uliginosum* seed, (11) *Arctagrostis latifolia* [local] seed, (12) *Ledum groenlandicum* seed.

This study was initiated to assess the potential of selected locally-collected native shrub and herb species and selected commercially-available species for use in Subarctic revegetation programmes. The approach taken was to sow seed on a simulated pipeline trench, located in the Subarctic boreal forest, to evaluate establishment potential and performance differences due to species and cultivation programmes. The effects of fertilization were also evaluated. In this paper we will report on the productivity (phytomass or above-ground biomass) component of the study. The cover, shrub plantings and native species invasion components will be the subject of future papers.

Study Area

At the SEEDS (Studies of the Environmental Effects of Disturbances in the Subarctic) research site, 10km north of Fort Norman, a 25-m-wide right-of-way (ROW) was cleared in a 200-year-old, Subarctic, *Picea mariana*-dominated forest (Figure 1). The area was underlain by permafrost and Gleysolic Turbic Cryosol soils (Kershaw and Evans 1987). A 2-m-wide simulated pipeline trench was installed within ROW 2 (Figure 2) during July and August 1986 and remained untreated for the remainder of that season. Natural revegetation was negligible by the end of 1986. Pre-disturbance soil conditions were found to be highly variable on the site. Five soil horizons were present: a fibric Of, a slightly decomposed Om, a discontinuous Bm, a gleyed-cryoturbated Cgy, and a perennially frozen Cz. The mean pH of each horizon increased with depth, ranging from 6.5 in the Of horizon to 7.2 in the Bmz horizon (Evans *et al.* 1988).

The trench was hand-excavated to an average depth of 50 cm and was immediately backfilled with the material that was originally excavated, resulting in complete alteration of the original soil profile, and random blending of the organic and mineral soils. Although post-excavation soil samples were not taken, the pre-excavation variability seen on the site was likely increased after excavation due to this mixing. The trench surface, though dominated by exposed mineral soil, was heterogeneous with respect to moisture, organic content, and microtopography.

Methods

Species Selection and Experimental Design

Seven herbaceous and shrub species that are commonly found in Subarctic forests, and that had successfully established on disturbances near the study area, were selected for testing: herbaceous - *Arctagrostis latifolia* (R.Br.) Griseb., *Carex membranacea* Hook.; shrubs - *Arctostaphylos rubra* (Rehn. & Wils.) Fern., *Betula glandulosa* Michx., *Empetrum nigrum* L., *Ledum groenlandicum* Oeder and *Vaccinium uliginosum* L. s.lat. (nomenclature follows Porsild and Cody 1980). During the summer of 1986, seeds of each species were hand collected from randomly-selected plants growing on local seismic lines. The seeds were stored in the field, in paper bags and were air dried. In September, they were moved to the lab, placed in plastic bags and stored at -23°C, until May 1987, at which time the seeds were removed from cold storage, cleaned and weighed in preparation for seeding. Additional species, that are native to the North and are currently being cultivated by experimental seed farms, were selected for field testing based on seed availability and discussions with the research centres where they were obtained (Table 1). All seeds were taken to the study site, where they were stored for 3 weeks, at ambient temperatures, while the revegetation plots were prepared.

In May 1987, while the ground remained frozen, *E. angustifolium* rhizomes were collected from local seismic lines and a burned area 5 km from the study site. The rhizomes were put in cold storage (buried under the snow) where they remained dormant until planting.

Using the above species, a total of 23 revegetation treatments were designed for field testing (Table 2). With the exception of the control, each of the species was tested both with and without fertilizer. Most were tested in separate treatments to allow for accurate identification of seedlings and to control for the effects of competition, however, the easily distinguished cultivated species were sown as mixes. Seeding rates were determined by the germination rates achieved in previously conducted growth chamber germination experiments, seed weights and recommended seeding rates (Hernandez 1973; Johnson 1981; Kubanis 1982). In some cases (e.g. *A. latifolia* local) allowances were made for chaff that was mixed in with some of the locally collected seeds. Seed coats of *A. rubra*, *E. nigrum* and *V. uliginosum* seeds were mechanically scarified using sandpaper; seeds from the other species were not treated in any way.

Table 1: Cultivated varieties obtained from seed farms.

SPECIES	ORIGIN OF SEED STOCK
Arctagrostis latifolia[1] var. Alyeska Polargrass	Alaska
Artemesia Tilesii Ledeb.[1]	Alaska
Calamagrostis canadensis[1] (Michx.) Beauv. var. Sourdough Bluejoint	Alaska
Decora Grass Seed Mix:[2]	
Agropyron violaceum (Hornem.) Lange -82%,	Northern Alberta
Festuca ovina L.-10%	Northern Alberta
Poa alpina L.-5%,	Alaska
Poa glauca M. Vahl -3%,	Alaska

[1] Provided by The Alaska Plant Material Centre, Palmer, Alaska
[2] Provided by Decora Landscaping Ltd., Whitehorse, Yukon

Forty-eight revegetation plots (2 x 3 m each) were established on the trench in ROW 2 (Figure 2). Between 21 May and 30 May 1987, immediately following snowmelt on the trench, each of the 23 revegetation treatments was applied to plots in duplicate. The control plot was replicated 3 times. Treatments were assigned to plots at random, however, to control for possible transportation of fertilizer to unfertilized plots, by runoff, all of the treatments that included fertilizer were grouped together on the east-west section of the trench (Figure 2). Seeds were hand broadcast onto the plots. The *E. angustifolium* rhizomes were cut to lengths of 25-60 cm, and all lateral roots and shoots were trimmed. Rhizomes were buried at a depth of approximately 5 cm, in rows at 10 cm intervals, beginning 5 cm in from the trench edge. Planting density varied from 25 to 35 per plot. One to 10 days prior to application of the treatments N-P_2O_5-K_2O (17:25:15) fertilizer was hand broadcast onto the designated plots, at a rate of 25 g m^{-2} (250 kg ha^{-1}). The fertilizer and application rate were the same as that used on Interprovincial Pipe Line's Norman Wells project (Wishart 1988).

Table 2: Revegetation treatments applied to trench surface.

TREATMENT	SOURCE	SEEDING RATE (g m^{-2})
Arctagrostis latifolia seed (reed polar grass)	local	3.50
Arctagrostis latifolia seed (Alyeska Polargrass)	seed farm Alaska	2.50
Carex membranacea seed (fragile sedge)	local	1.50
Artemisia Tilesii seed (mountain wormwood)-56% and *Calamagrostis canadensis* seed (sourdough bluejoint)-44%	seed farm Alaska	2.75
Decora grass seed mix: *Agropyron violaceum* (violet wheatgrass)-82%, *Poa alpina* (alpine bluegrass)-5%, *Poa glauca* (glaucous bluegrass) -3%, *Festuca ovina* (sheep fescue)-10%	seed farm Yukon	3.00
Epilobium angustifolium rhizomes (fireweed)	local	4-6 rhizomes
Arctostaphylos rubra seed (red fruit bearberry)	local	8.00
Betula glandulosa seed (glandular birch)	local	8.00
Empetrum nigrum seed (crowberry)	local	4.00
Ledum groenlandicum seed (Labrador tea)	local	0.50
Vaccinium uliginosum seed (bilberry)	local	6.50
Untreated Control		no seed

Assessment of Performance

A buffer zone of 10 cm was established around the periphery of each of the revegetation plots to control for the removal of soil and seed that had occurred along the edges of the trench through fluvial erosion. This zone was exempt from all sampling.

Phytomass was estimated for each of the treatments where the trial species achieved a plant cover >1%. Six treatments did not meet this criterion - *C. membranacea, A. rubra, B. glandulosa, E. nigrum, L. groenlandicum* and *V. uliginosum.* Five 25 x 25 cm quadrats, were randomly located within each 1.8 x 2.8 m revegetation plot using a random numbers table, for a total of 10 samples from each treatment. All above-ground portions of vascular plants rooted within the quadrats were collected. The phytomass was then sorted into 2 categories: trial species and other species. Samples were stored in paper bags in the field and air dried. In September, samples were oven dried, at 39°C, for 24 h in the laboratory before being weighed to the nearest 0.01 g.

For those revegetation plots in which the trial species was present at <1% cover, species density and frequency, rather than phytomass, were estimated, using 5 randomly located 25 x 25 cm quadrats in each 1.8 x 2.8 m revegetation plot, for a total of 10 samples from each treatment.

Data Analysis

All data were tested for normality using the Kolomogorov-Smirnov test for goodness of fit (Zar 1974; Statistical Graphics Corp. 1985). Appropriate transformations to normality were used when necessary. Analysis of variance was used to test for differences among species and treatments for all data which were normally distributed or transformed. Homogeneity of variance was tested using Cochrane's C test and Bartlett's test (Sokal and Rohlf 1981; Statistical Graphics Corp 1985). Differences in means were tested using Tukey's Multiple Range Test (Sokal and Rohlf 1981; Statistical Graphics Corp. 1985).

Results

Phytomass

With the exception of the fertilized Alyeska polargrass, which produced greater phytomass (68.38 g m^{-2}, $P<0.05$) than any other trial species, there was no difference among treatments in above-ground production by trial species (Table 3). Fertilizer applied to the Alyeska polargrass treatment resulted in a mean increase in phytomass of 663%, relative to the unfertilized treatment. This was the only treatment in which fertilizer affected above-ground production by the trial species, although a trend toward increased production was present for every species except *A. Tilesii* and *C. canadensis*. For six treatments, the amounts produced were not quantifiable due to the extremely low success. Variation (standard deviation) in phytomass was high for each trial species, indicating that production within the treatments was uneven. Some of this variation appeared to be a function of fluvial erosion. Although the effects of runoff were apparent along the entire trench, erosion was most prevalent in the north-south section where 28% of the total plot surface area was identified as disturbed in August, compared to only 15% of the surface area in the east-west section of the trench.

Density and Frequency

Density and frequency were assessed for the 2 trial species, *B. glandulosa* and *L. groenlandicum*, that had some seedling establishment but achieved a mean per cent cover of <1%. First year emergence was high in all treatments involving these species. Mean seedling densities were 243 m^{-2} for *B. glandulosa* and 375 m^{-2} for *L. groenlandicum*; the difference between the 2 species was not significant (Table 4). Fertilizer did not affect seedling density of either species. The high standard deviations indicate that seedling distribution of both species was clumped, particularly for *L. groenlandicum*. Even with such high densities a frequency of <100% was recorded for *L. groenlandicum* in the fertilized treatment (Table 4).

Discussion

Treatment Performance

First year phytomass was low for all treatments except the fertilized Alyeska polargrass. This may in part be due to the effects of fluvial erosion. Cover was significantly lower on areas of the trench that were eroded. Including these areas in phytomass sampling likely lowered the mean phytomass values. The Alyeska polargrass that received fertilizer was the only treatment where disturbed substrate was not present.

Table 3: Mean phytomass (g m^{-2})(SD) of trial species in each treatment at the end of the first growing season.

TREATMENT	n	TOTAL (SD)	TRIAL SPECIES (SD)
Arctagrostis latifolia Alyeska Polargrass			
F[1]	10	72.23 **a** (44.88)	68.38 **a** (45.85)
UF[2]	10	17.68 **bc** (7.67)	10.32 **b** (6.15)
Arctagrostis latifolia Local			
F	10	16.73 **bc** (9.01)	14.72 **b** (8.96)
UF	10	8.83 **bc** (4.55)	1.00 **b** (1.31)
Artemisia Tilesii and *Calamagrostis canadensis*			
F	10	12.63 **bc** (8.52)	AT[3]: 8.00 **b** (6.40) Cc[4]: 3.41 **b** (3.65)
UF	10	15.81 **bc** (8.95)	AT: 6.82 **b** (6.39) Cc: 4.86 **b** (5.60)
Decora Mix			
F	10	24.07 **b** (15.86)	22.02 **b** (14.25)
UF	10	8.07 **bc** (7.54)	4.98 **b** (6.84)
Epilobium angustifolium			
F	10	15.18 **bc** (20.81)	12.59 **b** (20.54)
UF	10	10.52 **bc** (14.69)	0.74 **b** (1.60)
Untreated Control			
UF	14	1.81 **c** (2.39)	--

[1] F-Fertilized [2] UF-Unfertilized
[3] AT-*Artemisia Tilesii*, [4] Cc-*Calamagrostis canadensis* Note: Means in the same column, with the same letters are not significantly different (P>0.05)).

The performance of the fertilized Alyeska Polargrass was superior to any of the other trial species. Concurrent testing of the locally collected *A. latifolia* and the variety Alyeska polargrass indicated that selection and cultivation programmes have enhanced the

Table 4: Mean seedling density (m^{-2}) and frequency (FQY), of species that achieved seeded cover values <1%, but >0%.

TREATMENT		n	DENSITY	FQY (%)
Betula glandulosa				
	F[1]	12	316 (271.0) **a**	100
	UF[2]	12	252 (218.5) **a**	100
Combined		24	284 (243.0) **a**	
Ledum groenlandicum				
	F	12	207 (326.7) **a**	83
	UF	12	459 (390.5) **a**	100
Combined		24	333 (374.9) **a**	

[1]F-Fertilized, [2]UF-Unfertilized, Note: Means with the same letter are not significantly different (P=0.05).

ability of this species to rapidly accumulate phytomass on exposed mineral soil. Even when unfertilized, Alyeska polargrass performed as well as the fertilized local *A. latifolia.*

Each of the other cultivated species also performed as well as, or better than the local *A. latifolia.* Each of these species germinated and established well, however, they were slow to develop and produce significant phytomass, relative to Alyeska polargrass.

The relatively poor performance by the Decora Seed Mix appeared to be primarily due to the slow growth rate of two component species, *A. violaceum* and *F. ovina.* However, based on the apparently successful seedling establishment by all 4 species, second year production is expected to be significantly higher for each of the species comprising this mix and the combination of the 2 rapid and 2 relatively slowly-establishing species that comprise the Decora Seed Mix should result in high long-term production.

The transplanted and fertilized *E. angustifolium* rhizomes were successful in producing phytomass while the unfertilized rhizomes were not. Three explanations emerge: the rhizomes did not survive the transplant, they were eroded from the plot or, during the first year following disturbance the limited available nutrients in the unfertilized plots were allocated primarily towards below-ground production, rather than production of new tillers. If the third explanation is correct then cover in the unfertilized plots may increase during subsequent years.

B. glandulosa and *L. groenlandicum* successfully established during the first growing season, however, seedling development of both species produced little phytomass. The high rates of germination conform to those observed by Karlin and Bliss (1983) which was reasonable since the substrates were ideal for germination (fine-grained, moist soils), no shading was present and the seed was collected locally and sown shortly after collection (Karlin and Bliss 1983).

The inability of the other shrub species - *A. rubra, E. nigrum,* and *V. uliginosum,* to establish from seed on the test plots appeared to be the result of poor germination success. It is not known if the seeds were inviable or dormant. The shrub seeds were planted without stratification in the hope that after being stored at ambient temperature on site for approximately three weeks they would germinate under the natural conditions encountered in the field. In Alaska, each of these species has been observed to naturally colonize exposed mineral soil from seed (Densmore 1979), and each successfully germinated after either 1 or 2 seasons when planted untreated in the field (Densmore 1979). If the poor germination seen in this experiment was due to seed dormancy rather than inviable seeds, it is possible that these species will germinate after the second growing season. Although mature *C. membranacea* individuals were found on several of the revegetation plots, the *Carex* seeds sewn in this experiment did not germinate.

Erosion Control Potential

Species suitable for short-term fluvial erosion control must be able to establish rapidly and root profusely during the first growing season. The degree of rooting necessary to control erosion is, of course, dependent on site characteristics, however, in the absence of severe runoff erosion, on flat to gently-sloping areas, Younkin and Martens (1987) conclude that approximately 40% live seeded cover would likely provide adequate erosion control for most situations. Based on performance during the first growing season, Alyeska polargrass is the only one of the trial species (and varieties) considered to have potential for this purpose, and even this variety is only suitable when fertilized. First year phytomass of 68.38 g m^{-2} produced by the fertilized Alyeska polargrass should contribute significantly to soil stabilization, although in areas with high erosion potential, such as pipeline trenches or ice-rich slopes, engineering measures will likely be required (Wishart 1988).

The significant above-ground production by Alyeska polargrass will contribute to a higher total cover in the second year by producing ground cover in the form of litter.

Alyeska polargrass is known to be suitable for use in reclamation programmes in Alaska (Millar *et al.* 1983). First year performance of Alyeska polargrass in this study suggests that this variety is also suitable for use on permafrost-affected soils in Subarctic boreal forest habitats.

Effects of Fertilizer

The effects of fertilizer on native plant species has recently been reviewed (Walker *et al.* 1987). In our study, fertilizer application resulted in increased mean phytomass in all of the trial species but, with the exception of Alyeska polargrass, the values were not significantly different from unfertilized treatments. Therefore, on the basis of phytomass, fertilizer cannot be considered essential to the success of the other trial species, and is not recommended for use in the first year. During the second growing season, some positive effects of the fertilizer may become apparent, which would then alter this recommendation. Fertilizer had no effect on seedling establishment or growth of *B. glandulosa* or *L. groenlandicum*. Once seedlings have produced an extensive root system, fertilizer may positively affect production, however, the fertilizer may be unavailable to plants by the second growing season due to its removal by running water or other agents.

In some cases, the results of fluvial erosion confounded the effects of fertilizer application. The role of running water in eroding soil, seed and fertilizer was likely underestimated. Although the survey method provided an accurate measure of the fluvially-disturbed substrate present in August, it would have been difficult to identify areas similarly affected early in the season (immediately following snowmelt) since these areas quickly restabilized after the peak in runoff occurred. Plots that had been so affected would have lost some or all of the seeds, rhizomes or fertilizer available for revegetation. It may be that the low production achieved on the unfertilized plots was due in part to this phenomena. However, the high seedling density seen on some of the unfertilized treatments (e.g. *B. glandulosa* and *L. groenlandicum*) suggests that, on at least some of the plots, erosion of seed was not a problem.

Conclusions

Based on productivity and seedling densities we conclude that *A. latifolia* (local and Alyeska polargrass), the Decora Seed Mix (*A. violaceum, F. ovina, P. alpina, P. glauca*), *C. canadensis, A. Tilesii, B. glandulosa* and *L. groenlandicum* are suitable for use in revegetation programmes of exposed mineral soils in Subarctic areas with low erosion potential. Alyeska polargrass is also suitable for erosion control purposes on areas with moderate erosion potential. However, using the same criteria, we concluded that *C. membranacea, A. rubra, V. uliginosum* and *E. nigrum* are not suitable for revegetation programmes. Planting *E. angustifolium* rhizomes appears to have potential for accelerating the establishment of vegetation, if used with fertilizer.

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REVEGETATION IN THE CANADIAN NORTH - A 15 YEAR PERSPECTIVE

SUMMARY OF FINDINGS

by

H. Martens[1] and W. Younkin[2]

Introduction

Reclamation studies in the Canadian North were begun in the early 1970's in response to the increased pace in the search for oil and gas. Since then a wide range of studies and trials have been conducted over a broad and highly diverse geographic area. Because of the harshness of the Northern environment and a lack of adapted plant material, the major emphasis in reclamation research was on revegetation--the establishment of a protective plant cover. Studies included trials of species, seed mixes, fertilizers, sod stripping and replacement, mulches etc. Although many of these studies were essentially abandoned after fulfilling short-term practical goals, long-term observations have provided a great deal of useful information. We at Hardy BBT Limited have been fortunate to have been involved in the establishment and long term assessment of many of these studies. The following is a summary of the major findings by category:

Species and Seed Mixtures

1. A sizable list of commercially available species of grasses and legumes, useful for revegetation in forest regions, is available and expanding (Table 1). In the woodland and tundra regions, legumes drop off the list and the number of grasses is somewhat lower yet still significant (Tables 2 and 3). No revegetation species have been identified for polar desert regions.

2. Although native grasses have made significant contributions to northern revegetation efforts, the majority of successful species are selections from northern adapted commercial stocks.

3. Generally better adapted species are slower to establish and less responsive to fertilizer additions while less hardy species tend to provide

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Table 1. Revegetation Species for the Forest Region

	Moisture Preference*	High Initial Cover**	Low Initial Cover
Bentgrass			
Highland Colonial	M-W	X	-
Creeping bentgrass	M-W	X	-
Common redtop	M-F	X	-
Bluegrass			
Common Kentucky	M-W	-	XX
Icelandic Holt	M-W	-	XX
Fescue			
Boreal creeping red	M-D	-	XX
Arctared creeping red	M-D	-	XX
Durar hard	M-D	-	XX
Foxtail			
Common creeping	M-F	XX	-
Common meadow	M-F	XX	-
Smooth bromegrass			
Carlton	M	XX	-
Manchar	M	XX	-
Reed Canarygrass	M-F		
Frontier		XX	-
Vantage		XX	-
Timothy			
Climax	M-D	X	-
Engmo	M-D	X	-
Rye (Spring or Fall)	M-D	X	-
Wheatgrass			
Fairway crested	M-D	-	X
Nordan crested	M-D	-	X
Revenue slender	M-D	XX	-
Sodar streambank	M-D	XX	-
Critina thickspike	M-D	-	X
Alfalfa	M-D		
Anik		-	XX
Drylander	-	-	XX
Sainfoin			
Nova	M-D	-	XX
Melrose	M-D	-	XX
Clover			
Aurora alsike	M-W	-	XX
White Dutch	M	-	XX

* Moisture - D-dry; M-mesic; W-wet; F-prolonged flooding

** X - Maintains 15-20% live cover for approximately 5 years.
XX - Maintains 15-20% live cover in excess 10 years.

Table 2. Revegetation Species for the Woodland Region

	Moisture Preference*	High Initial Cover**	Low Initial Cover
Bentgrass			
Highland Colonial	M-W	X	-
Creeping bentgrass	M-W	X	-
Common redtop	M-F	X	-
Bluegrass			
Nugget Kentucky	M-W	-	X
Fowl	M-W	XX	-
Icelandic Holt	M-W	-	XX
Fescue			
Boreal creeping red	M-D	-	XX
Arctared creeping red	M-D	-	XX
Durar hard	M-D	-	XX
Foxtail			
Common creeping	M-F	XX	-
Common meadow	M-F	XX	-
Smooth bromegrass			
Carlton	M	-	X
Reed Canarygrass	M-F		
Frontier		X	-
Vantage		X	-
Timothy			
Engmo	M-D	X	-
Rye (Spring or Fall)	M-D	X	-
Wheatgrass			
Revenue slender	M-D	X	-
Sodar streambank	M-D	X	-

* Moisture - D-dry; M-mesic; W-wet; F-prolonged flooding

** X - Maintains 15-20% live cover for approximately 5 years.

XX - Maintains 15-20% live cover in excess 10 years.

Table 3. Revegetation Species for the Tundra Region

	Moisture Preference*	High Initial Cover	Low Initial Cover**
Bentgrass			
Highland Colonial	M-W	X	-
Common redtop	M-F	X	-
Bluegrass			
Nugget Kentucky	M-W	-	XX
Canon Canada	D-W	-	X
Tundra	D-W	-	XX
Icelandic Holt	M-W	-	XX
Fescue			
Boreal creeping red	M-D	-	X
Arctared creeping red	M-D	-	XX
Durar hard	M-D	-	X
Foxtail			
Common creeping	M-F	X	-
Smooth bromegrass			
Carlton	M	-	X
Reed Canarygrass	M-F		
Frontier		X	-
Timothy			
Engmo	M-D	X	-
Rye (Spring or Fall)	M-D	X	-
Wheatgrass			
Revenue slender	M-D	X	-

* Moisture - D-dry; M-mesic; W-wet; F-prolonged flooding
** X - Maintains 15-20% live cover for approximately 5 years.
XX - Maintains 15-20% live cover in excess 10 years.

rapid cover prior to winter kill.

4. Similar to more temperate regions, seed mixes improve the chances of success of revegetation efforts in the north. Long term observations in tundra regions suggest that a mixture of rapidly establishing but less hardy species with generally slower establishing winter hardy species provides both a rapid and long-lasting protective cover while allowing native species to invade gradually.

Shrub Cuttings

5. Shrub cuttings of locally available willow, birch, alder and dogwood established at Sans Sault, NWT in 1971 and 1972 demonstrated that over a 12 year period, willow (Salix alexensis) had by far the highest survival rate. Only willow (96%) and alder (Alnus crispa) survived to year three with willow achieving heights of over 2 m by year 12.

6. Observations of shrub cuttings over two seasons along the IPL Norman Wells to Zama pipeline demonstrated that Salix interior had the highest survival (82%) on moist, sandy slopes, while Salix alexensis had the highest survival (80%) on wet clay-loam soils. Growth of all species was poorest and mortality highest in areas with ponded water.

Fertilizer Formulation and Application Rate

7. Most northern areas are uniformly low in plant nutrients and complete fertilizers containing N, P_2O_5, and K_2O, in a 1:2:1 ratio at 56, 112, and 56 kg per hectare respectively provide good initial growth.

8. In most northern regions fertilizer effects were not apparent by the second or third year following application, however, species well adapted to the northern climate such as Arctared creeping red fescue and Nugget Kentucky bluegrass still provided luxuriant growth and copious seed production 7 to 12 years following fertilization.

Seed and Fertilizer Rate Trials

9. In tundra regions increasing the seeding rate from 28 to 112 kg/ha for slow establishing but hardier species such as Nugget Kentucky bluegrass and Arctared creeping red fescue resulted in significant increases in first year cover (from a low of 8% to a high of 27% cover). Faster establishing but less hardy species such as Engmo timothy, were not as effected by seeding rate, producing high initial cover at even the lowest seeding rate (60%).

10. In the forest region the rate of fertilizer application was far more important in ground cover production than seeding rate, each increase in

fertilizer from 0 to 500 kg/ha resulting in significant increases in first year cover especially at the highest rate (Figure 1). By year two fertilizer effects were greatly deminished and by year four cover production was nearly the same in all plots.

Sod Stripping and Replacement Trials

11. Sod stripping and replacement was not judged to be successful in polar desert regions. Three years following stripping and replacement in a lowland meadow on Melville Island, vascular plant cover was only 1 to 2 percent vs. 43 percent in adjacent control areas.

12. In tundra near Tuktayaktuk, NWT replacement of sod in three plant communities: shrub-heath tundra, tussock tundra and sedge meadow, provided a fourth year plant cover similar in composition and total cover to native plant communities but with a generally higher proportion of grasses and sedges and lower proportion of evergreen and deciduous shrubs.

13. Replacement of sod maintained fourth year active layer thickness similar to undisturbed plant communities (averaging 27 cm) compared with 63 cm under areas where sod had not been replaced.

Effects of Seed and Fertilizer on Natural Recovery

14. The seeding of pure stands of hardy mat forming grasses such as Nugget Kentucky bluegrass and Arctared creeping red fescue significantly reduced the rate of invasion of native species in the tundra region (Figure 2).

15. Seeding of mixtures of short-lived rapid establishing grasses with more hardy mat-forming grasses allowed a rate of native species invasion similar to that of unseeded controls while providing a high level of protective cover (Figure 2).

16. In the forest region the application of seed and fertilizer significantly retarded the establishment of native species. Although native species cover was nearly equal on both seeded and fertilized plots and unseeded control plots the first year (8%), by the fourth year native species provided three times more cover on control plots (30%) than on seeded and fertilized plots (10%) (Figure 3).

17. Although unseeded and unfertilized control plots were more encouraging to the establishment of native species, the amount of protective plant cover established was significantly lower in all years studied than in the seeded and fertilized plots (16% vs. 40% in year 2 and 34% vs. 65% in year 2).

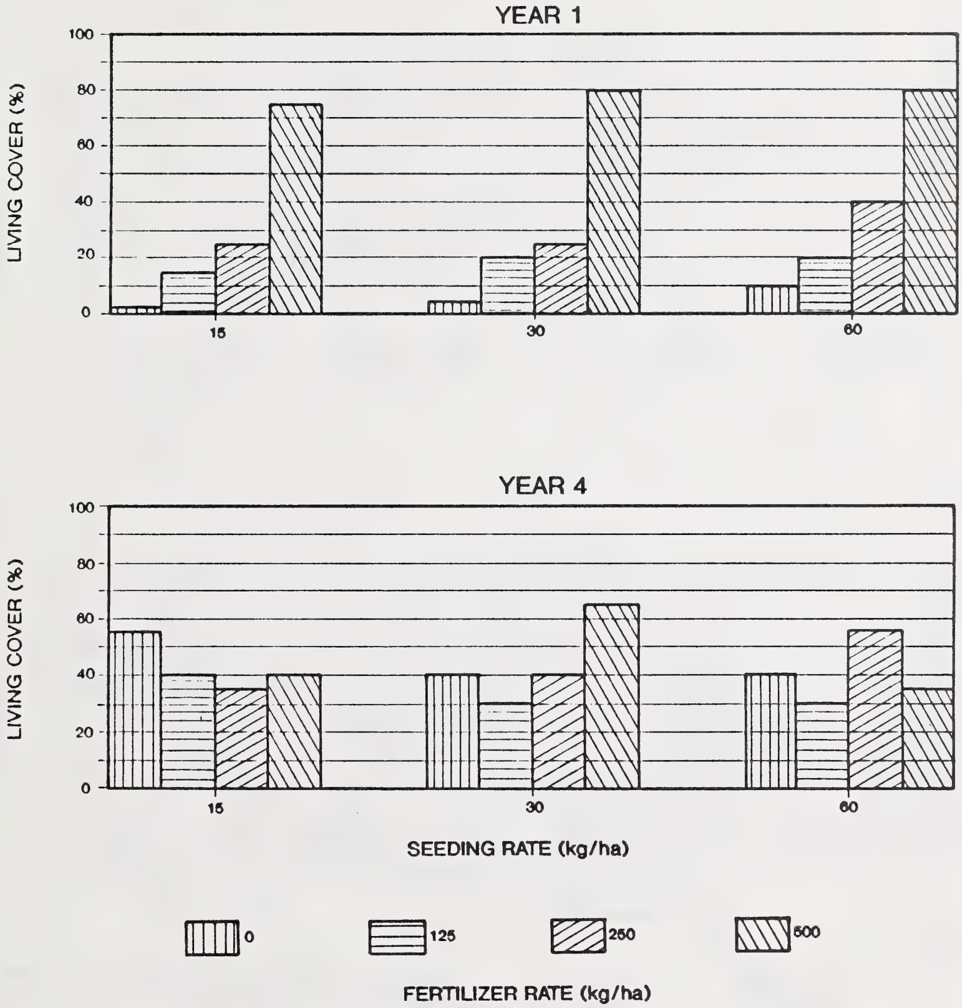

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Figure 1. Percentage Living Cover on the Seed and the Fertilizer Rate Study Established on the IPL Norman Wells to Zama Pipeline in 1984.

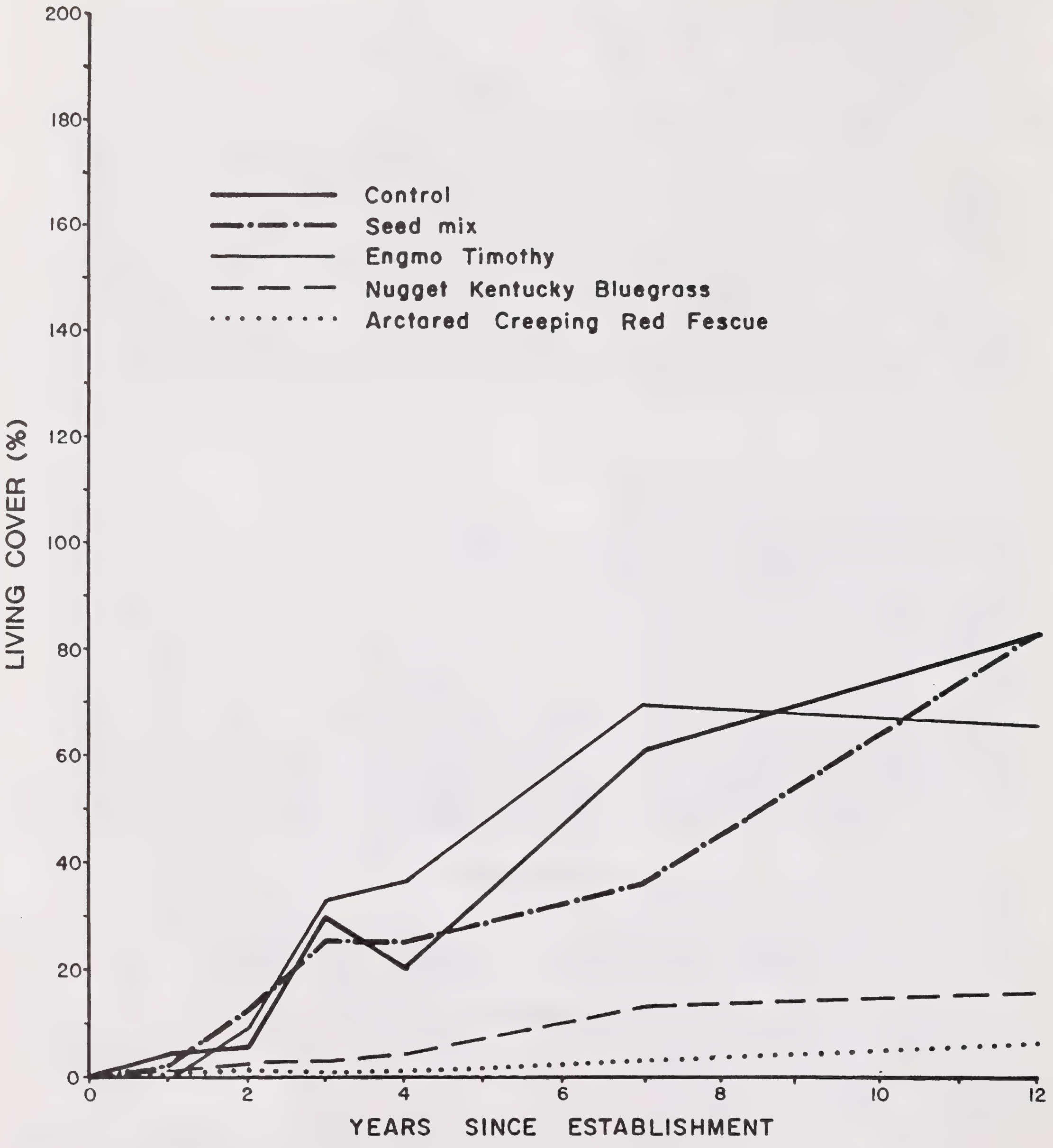

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Figure 2. Percent Living Cover of Native Invaders.

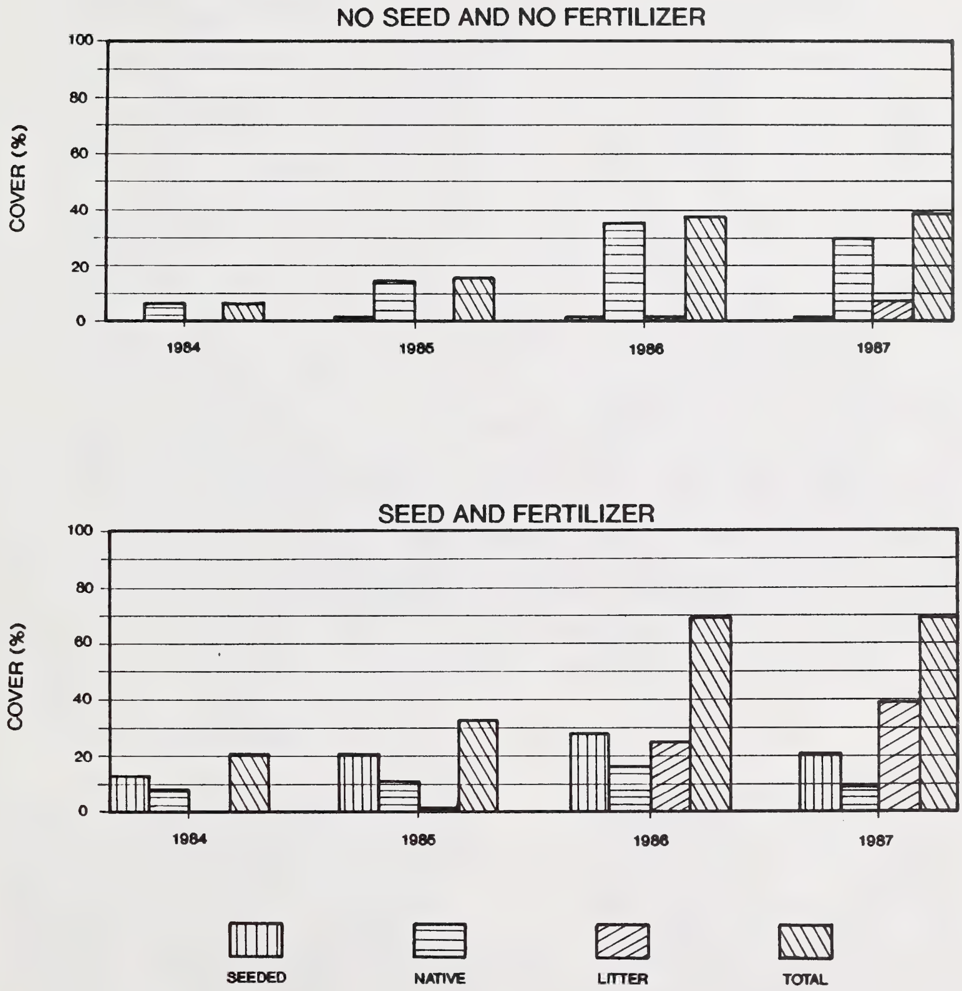

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Figure 3. Percentage Cover by Plant Cover Category on Revegetation Trial Sites on the IPL Norman Wells to Zama Pipeline Treated in 1984.

RECLAMATION CHALLENGES AT USIBELLI COAL MINE IN HEALY, ALASKA[1]

by

Larry P. Jackson[2]

Abstract. Reclamation in a subarctic environment requires a thorough understanding of the effect of subzero temperatures on soil, water and vegetation. Usibelli Coal Mine's Poker Flats mine is located in an area that contains zones of permafrost. The presence of permafrost requires study due to the fact that once it is disturbed it will eventually thaw. The type of material the permafrost is comprised of determines the options you have in stabilizing and maintaining vegetation on it. Once an analysis of soil conditions is conducted, a more detailed study is done to determine what type of water control measures need to be considered given the presence of frozen, ice-rich ground. The water control measures to be implemented are usually untested in the field. This leads to both pleasant and unpleasant results. The water control plan incorporates erosion control measures. Erosion control is one of the most challenging aspects of reclamation in the Healy area, as the Hoseanna (Lignite) Creek drainage has one of the highest rates of natural erosion in the world. One of the key components of maintaining a successful reclamation program in Alaska is to not have any preconceived idea of what is going to happen next. Each project that is designed and implemented usually involves procedures that have never been tried in this particular environment. Because there is little or no precedent for these types of projects, every day is an adventure.

Introduction

Usibelli Coal Mine, Inc. has been a pioneer in Alaskan reclamation since the spring of 1971. It was then that Usibelli Coal Mine, under the direction of Joseph E. Usibelli, contracted with Canadian agronomist Stanley Weston of Vancouver, British Columbia to act as an advisor in its initial reclamation endeavors. These early experiments included the establishment of grass test plots on mined areas to assess optimum grass and fertilizer combinations. The results of this research led to reclamation of over 650 ha (1600 ac) of mined land in 1972 and 1973 and subsequent reclamation of over 1600 ha (4000 ac) through 1989. Much of the information obtained from this work was later utilized in reclamation projects on the Trans-Alaska Oil Pipeline. To exemplify Usibelli Coal Mine's commitment to reclamation, it should be noted that Usibelli Coal Mine initiated reclamation six years prior to the passage of the Surface Mining Control and Reclamation Act (PL 95-87) by Congress in 1977.

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[1] Paper presented at the conference Reclamation, A Global Perspective, held in Calgary, Alberta, Canada August 27 - 31, 1989.

[2] Larry Jackson is the Reclamation Engineer employed by Usibelli Coal Mine, Inc., Box 1000, Healy, AK 99743.

Usibelli Coal Mine's reclamation activities today center around the mining of coal in the lower Hoseanna (Lignite) Creek Basin located 177 km (110 mi) southwest of Fairbanks and 6 km (4 mi) north of Healy, in an area known as Poker Flats. The Poker Flats site is situated at 149 degrees 57 minutes west latitude and 63 degrees 54 minutes north longitude in the low mountains at the north foot of the Alaska Range.

Poker Flats is located south of Hoseanna (Lignite) Creek with predominantly north-facing slopes underlain by zones of discontinuous permafrost and has numerous natural landslides. Premining slopes range from 1 to 60 degrees in grade. Many of the steeper slopes are the result of erosion of sandstone into the natural "badlands" land form. Elevations at Poker Flats range from 366 m (1200 ft) to 610 m (2000 ft).

Mining at Poker Flats commenced in 1978 utilizing a $25m^3$ (33 cy) walking dragline that strips two coal seams using an extended bench on the second pass. Coal production at Usibelli Coal Mine is currently 1.3 Mt/a (1.5 million stpy). Half of the coal produced is used in Alaska by small powerplants located in Healy, Clear and Fairbanks. The remainder is exported to South Korea through the Seward Coal Terminal for use at the 560-megawatt Honam power plant.

The effect of the subarctic climate in association with the physical and chemical properties of the geologic strata involved in mining has a profound effect on reclamation planning and subsequent revegetation. The purpose of this paper is to share some of the reclamation challenges that have arisen at the Usibelli Coal Mine Poker Flats operation.

Climate

Poker Flats climate is classified as Transitional as defined by Searby (1960) and subarctic if forest types are used to differentiate climatic zones. Transitional climates are characterized by significant diurnal and annual temperature variations, low precipitation, low cloudiness, and low humidity. Mean annual temperatures range from -3.9° to 1.7°C (25° to 35°F). Subarctic lands are distinguished by moderate and sparse forests and have from one to four months with monthly mean temperatures greater than 10° C (50°F) and at least one month with a mean temperature of 0°C (32°F) or colder.

Table 1 shows that the mean annual temperature for Poker Flats is 2.6°C (27.4°F). The lowest and highest mean monthly temperatures February, -15.7°C (3.7°F) and July, 12.8°C (55.0°F). With 7 out of 12 months below 0°C (32°F), climatic conditions are favorable for finding permafrost, especially on north-facing slopes and areas with moss vegetative cover.

Table 1. The Monthly Mean Temperatures (1979-1988) in °C

Month	Temperature
January	-14.0
February	-15.7
March	- 8.4
April	- 3.3
May	5.6
June	10.7
July	12.8
August	9.8
September	4.3
October	- 5.3
November	-13.2
December	-14.3
Mean Annual	- 2.6

Precipitation ranges from 38 cm (15 in) to 51 cm (20 in) annually. Most of the moisture is received in the form of rain during May to September. High intensity rainfalls are not uncommon. During one storm on June 18, 1988, Poker Flats received 3.3 cm (1.28 in) in 45 minutes. Snowfall quantities range from 76 cm (30 in) to 152 cm (60 in) per year. Most of this snow never has the opportunity to be utilized by plants. The Healy vicinity is famous for its Chinook winds. These winds are associated with low pressure systems and generally bring temperatures that are above freezing. Wind gusts of 22 m/s (50 mph) to 36 m/s (80 mph) are not uncommon. The above freezing temperatures combined with high winds sublimate the snow, resulting in very little water absorbing into the soil.

Geology

The Poker Flats mining area is located in the lower Hoseanna (Lignite) Creek Basin which makes up a portion of the Nenana Coal Field. The coal-bearing group at Poker Flats is of Tertiary age and is overlain by the Nenana Gravels. Over most of the mine area the Nenana Gravels have been eroded away and replaced by Quaternary outwash gravels. The coal-bearing group is divided into five formations: Healy Creek, Sanctuary, Suntrana, Lignite, and Grubstake (Wahrhaftig et al. 1969). The Healy Creek formation is the oldest unit and is of early Miocene age and the Grubstake is the youngest. Mining at Poker Flats takes place in the Suntrana formation. It contains six coal seams (designated 1-6, with the oldest (lowest) seam being assigned the number 1. Coal seams 6, 4, and 3 are currently being mined. Seam thicknesses average 6.4 m (21 ft) for seams 6 and 4, and 5.2 m (17 ft) for seam 3. On an as received basis, the coal from these three seams has an average heating value of 7800-8000 Btu/lb, 6-8% ash, 25-27% moisture and 0.1 to 0.3% sulfur.

Overburden and partings are typically coarse, pebbly sandstone, grading to fine sandstone and ending with a clay and silt bed. The sandstones are poorly consolidated and composed primarily of quartz, feldspar, and lithics (mostly mica, schist, and plutonic rock fragments).

The limits of mining at Poker Flats are defined by outcrops to the north, and to the south by a fault believed to have several thousand feet of vertical displacement.

Reclamation

Reclamation at Poker Flats can be divided into three phases. They are regrading, drainage control, and revegetation. All three are related and each one is influenced by the presence of permafrost.

Regrading plans were developed for Poker Flats to approximate the premining contours. Recontouring involves the grading of dragline spoils by a bulldozer. Initial reclamation efforts at Poker Flats began on the north-facing slope along the outcrops of 3 and 4 seams. The spoil material in this area is largely composed of ice-rich silt and sandstone. The physical properties of this material restrict the use of bulldozers to the months of December to April. During this time period, surface frost reaches up to 5 m (16 ft) in depth, making it necessary to rip the material in addition to pushing it. Usibelli Coal Mine estimates that this reduces production efficiency by one-third. Slopes are graded to a maximum slope of 18°(33%).

Upon completion of regrading, the next step is to prepare the planting medium for seeding and to install drainage control in order to minimize erosion. The planting medium utilized for the Poker Flats mine is the Suntrana sandstone. It was selected in lieu of the permafrost soils that predominate the mining area. The physical and chemical properties of the permafrost soils were analyzed, and they were immediately eliminated due to the fact that their thawed angle of repose ranged from 5 to 10 degrees. The best substitute material was determined to be the sandstone overburden and interburden. Table 2 summarized its chemical and physical properties.

Table 2. Suntrana Sandstone Chemical and Physical Properties

Parameter	Average Value (18 Samples)
pH	6.5
Ca	3.18 meq/1
Mg	1.70 meq/1
Na	2.77 meq/1
$N-NO_3$	1.28 ppm
PO_4	1.17 ppm
K	46 ppm
Organic matter	1.16%
Saturation	29%
Texture	Sandy loam - sand 65%, silt 27%, clay 8%
CEC	7.4 meq/100 g

The sandstone minesoil is prepared for seeding by installing contour furrows. This is accomplished by attaching a modified plow to the ripper teeth of a Caterpillar D-8 dozer and operating on the contour. The benefits of the furrows are as follows:

1. Reduces the velocity of surface water runoff.
2. Conserves moisture by trapping snow.
3. Serves as seed trap during broadcast seeding.
4. Assures a well-prepared seedbed that is not compacted.

In conjunction with the installation of contour furrows, Usibelli Coal Mine constructs a system of terraces and drains designed by Golder Associates (1987). These structures are designed to convey a 10-year, 24-hour rainfall event of 5 cm (2.0 in).

The terraces are spaced vertically every 15 m (50 ft) to 30 m (100 ft) depending on slope steepness. Terraces are designed to be 6 m (20 ft) wide and have a gradient of 2% and a backslope of 10%. Because of the erosive nature of the sandstone and the presence of ice-rich materials, the terraces are lined with a layer of gravel approximately 0.23 m (0.75 ft) in thickness.

The terraces slow into drains that are 6 m (20 ft) in width and trapezoidal in cross-section. The channel lining for the drains consists of rip-rap with a median size of 0.46 m (1.5 ft). Flow from the drains is conveyed to sediment ponds.

It is esimated using the universal soil loss equation that the effect of the furrows and terraces is a reduction in erosion by 700%.

The final step in the reclamation process is the reestablishment of a vegetative cover. The function of this cover is to initially control erosion and over time, allow the natural reinvasion of native species. The seed mix utilized by Usibelli Coal Mine is illustrated in Table 3.

Table 3. Poker Flats Seed Mix

Common Name	Kg/ ha	Lbs/ Acre
Manchar smooth brome	13.5	12
Scaldis hard fescue	9.0	8
Arctared or boreal red fescue	9.0	8
Nuggest bluegrass	9.0	8
Meadow foxtail	3.4	3
Anik or rhizoma alfalfa	9.0	8
Reed canary grass	2.2	2
Candle rape	2.2	2
Annual ryegrass	4.5	4
Total	61.8	55

Grass species have been chosen because of their ability to withstand the low temperatures, to establish quickly and to adapt to areas with high moisture content such as thawed permafrost materials. To assist in the establishment of the grass seedlings, fertilizer with an analysis of 20-20-10 (N-P-K) is added at a rate of 450 kg/ha (400 lbs/ac).

Seeding is conducted during the time period of May 15 - June 15. During this time of year it is not practical to operate equipment on areas that are composed of thawed permafrost soils. The method used to apply the seed and fertilizer is to broadcast the material using a fixed-wing aircraft. The advantages of aerial application are:

1. There is no damage to the regraded area due to equipment.
2. Steep grades are not a limiting factor.
3. It is cost effective.

After seeding, native shrubs and trees are collected and planted. Species planted include felt leaf willow, balsam poplar, alder and spruce. Sites for planting are chosen based on the moisture requirements of individual species. In soils with high moisture such as thawed permafrost zones, felt leaf willow and balsam poplar are planted. In areas that are drier, alder and spruce are preferred. These plants form the foundation for our postmining land use as wildlife habitat.

Summary and Conclusions

The ultimate test of the reclaimed land is whether it is going to be of benefit to wildlife. The results of over 18 years of reclamation effort by Usibelli Coal Mine, Inc. are encouraging. It is heartening to see wildlife returning to previously mined areas. The challenges of reclaiming land in this subarctic environment are being met. It is important that we understand the climatic and geologic features of the Hoseanna (Lignite) Creek Basin so that more rational environmental regulations are developed to suit this unique area. For Alaska's only producing coal mine to stay competitive, it is vital that we continue to improve reclamation techniques so that both a more effective and a more cost-efficient reclamation program is achieved.

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ADVANCES IN PLANT MATERIAL AND REVEGETATION TECHNOLOGY IN ALASKA[1],[2]

by

Stoney Wright[3]

Abstract. This paper is intended to be informative and descriptive, rather than purely conclusive. The paper will cover the gamut of revegetative and reclamation efforts being attempted by the Alaska Plant Materials Center throughout Alaska. These efforts include coastal and wetland restoration, cost-effective methods for willow reestablishment, and extention of seeding periods through the use of dormant or Fall seedings. New cultivars and adapted species of vegetation will also be addressed.

Additional Key Words: arctic, boreal and northern coastal reclamation.

Introduction

The Alaska Plant Materials Center (PMC) is a section of the Division of Agriculture within the Department of Natural Resources. In contrast to other PMCs, the Alaska center is fully state funded. Early attempts in establishing a federal Plant Materials Center in Alaska failed.

The PMC not only conducts revegetation oriented work, but also horticultural development, foundation seed production, and the Potato Disease Control project.

This paper is a composite of individual reports available from the Alaska Plant Materials Center. The intent of the paper is to present the state of the Alaska Plant Materials Center's reclamation and revegetation research. The paper will also present general revegetation recommendations and techniques in willow planting, wetland restoration, and coastal revegetation.

Methods

Since the establishment of the Alaska Plant Materials Center in 1972, in excess of 2,000 accessions of native and introduced plants have been screened and evaluated for conservation uses.

The PMC follows seven basic steps to establish a resource of conserva-

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[1] Paper presented at the conference Reclamation, A Global Perspective, held in Calgary, Alberta, Canada August 27 - 31, 1989.

[2] Publication in these proceedings does not preclude the author from publishing this manuscript, whole or in part, in any other publication.

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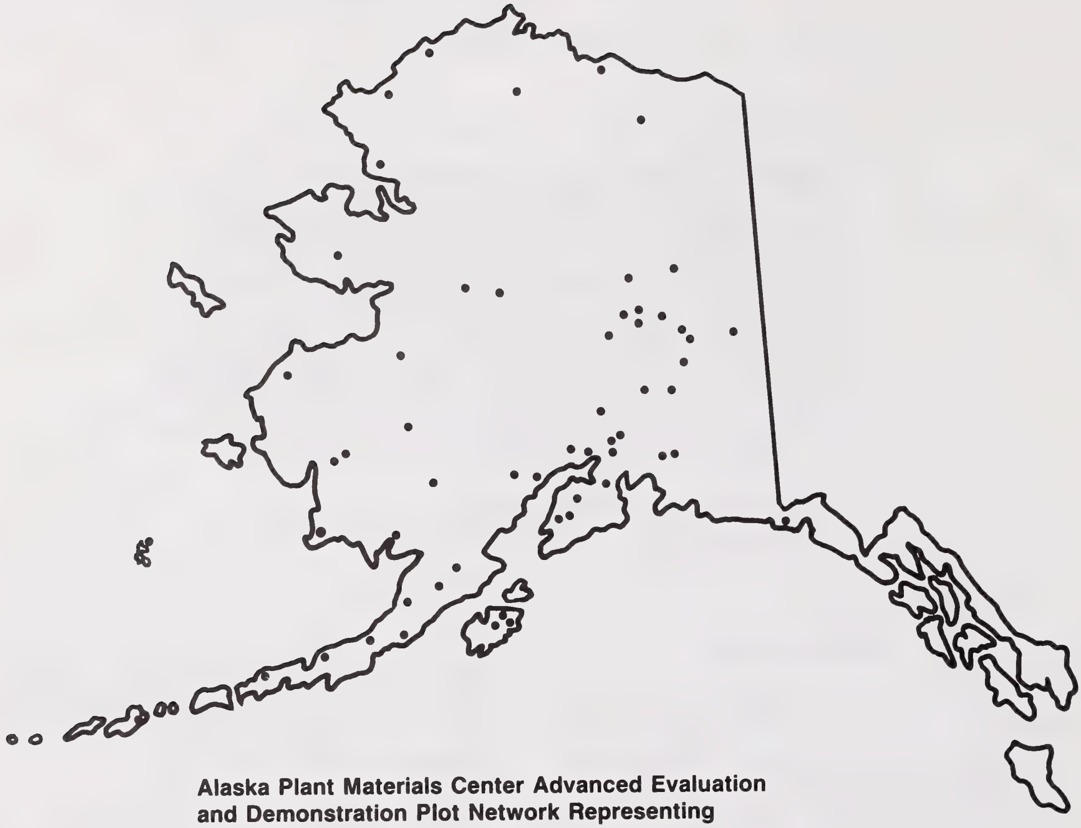

Alaska Plant Materials Center Advanced Evaluation and Demonstration Plot Network Representing 149 Plot Years as of 1987

FIGURE 1.

tion plants for use in land reclamation, wildlife habitat improvement and erosion control. They are: 1) define and anticipate conservation problems and establish priorities; 2) research and assemble candidate plant materials; 3) conduct initial evaluations; 4) establish small scale seed or vegetative increases; 5) conduct advanced and final testing and field evaluation plantings; 6) establish large scale seed or vegetative increases; and, 7) release of a variety or cultivar.

Of these steps, the most critical are the field evaluation plantings. This aspect of the program allows plant material to be evaluated in a wide range of edaphic and climatic conditions (Figure 1). Basically, this phase revolves around two classes of plantings, advanced evaluation and demonstration plots, and mining and industrial evaluation plots.

Advanced Evaluation and Demonstration Plots are established throughout Alaska for three purposes: 1) advanced or final evaluation of plant materials that have performed well at the Palmer PMC for a period of at least three years; 2) demonstration plantings of plant material already recommended for the area; and, 3) provide a centralized area for local plantings by the cooperative Extension agents and other cooperators.

Mining and Industrial Evaluation Plots are usually designed for reclamation and/or erosion control. The plots are developed in a manner consistent with the clients intended final management practice, i.e., "fertilize it once and forget about it." The plantings are made on the substrate that is expected to be available when reclamation occurs.

These plots also serve as an advanced evaluation of plant materials that have been selected at the PMC for their outstanding performance.

This class of evaluation plot probably provides the most important and useful information to the North Latitude Revegetation and Seed Project.

When an accession has proven to be superior through the evaluation process, and specific cultural and management techniques have been developed, the accession is released for commercial production.

Results: Releases, Recommendations and Technology Advances

New Releases

The evaluation network established by the PMC and the data collected from these plots has resulted in the release of two new grass cultivars and five willow cultivars. Within three years, an additional four grasses and one willow may be released.

The following cultivars have been released:

'Egan' american sloughgrass, Beckmannia syzigachne. 'Egan' was released for commercial seed production in 1986. This cultivar has performed well at most test sites. Its expected uses are wetland restoration and waterfowl habitat enhancement.

'Gruening' alpine bluegrass, Poa alpina. This selection of alpine bluegrass was released for production in 1987. A native species, alpine bluegrass has shown extreme hardiness throughout Alaska and is well adapted to harsh sites such as mine spoil (Wright 1985).

'Roland' pacific willow, Salix lasiandra. 'Roland' was released in 1985 and is probably the most attractive willow selected by the PMC to date. This cultivar will be used for landscaping, stream protection and revegetation throughout most of Alaska (Wright 1985).

'Wilson' bebb willow, Salix bebbiana. This willow has a dense growth form and has many potential uses for screening, windbreaks and living fences. Because of the the species' wide range of adaptability, it is also expected to be utilized for reclamation activities. 'Wilson' is a 1985 release (Wright 1985).

'Long' barclay willow, Salix barclayi. This attractive, fast-growing native willow was released for commercial production in 1985. This cultivar will be used for reclamation, landscaping and shelter belts (Wright 1985).

'Oliver' barren ground willow, Salix brachycarpa. 'Oliver' was released for commercial production in 1985. This cultivar's interesting growth form will lend itself well for incorporation into hedges. Additional uses range from reclamation to windbreaks (Wright 1985).

'Rhode' feltleaf willow, Salix alaxensis. 'Rhode' was also released for commercial production in 1985. This species occurs throughout Alaska and is listed as a preferred wildlife species. This cultivar will find uses in habitat restoration, reclamation, streambank protection and shelter belts (Wright 1985).

Revegetation Regions of Alaska

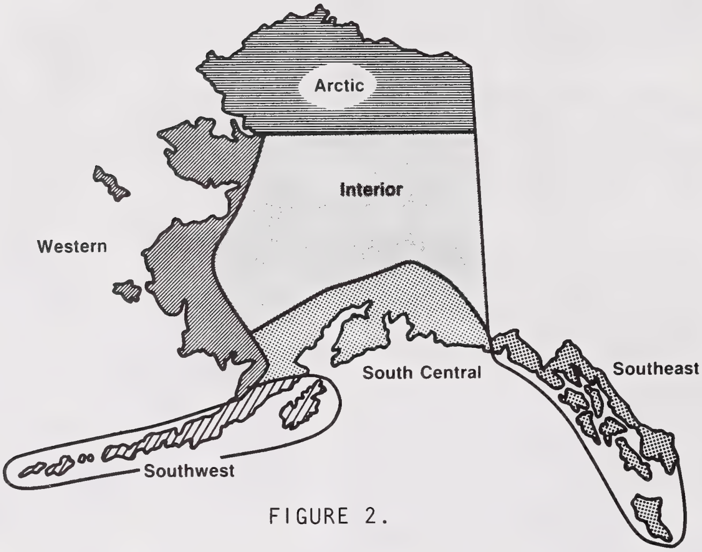

FIGURE 2.

Regional Recommendations

In addition to the new plant materials released for producton, the plot network has allowed a base of knowledge to be developed for revegetative recommendations. This systematic evaluation network has allowed for ground truthing and refining past standard recommendations and developing new recommendations based on regions. Figure 2 designates revegetation regions.

Findings of the PMC statewide evaluations are presented in Table 1 (Moore 1986a, b; Wright 1986a, 1987a, b, c, d, e, 1988a, b, c, d, 1989a, b).

As with all general regional revegetation recommendations, the Alaska Plant Materials Center does not suggest that these be followed without site specific refinement.

Specific site recommendations can be developed with specific information on soil conditions (texture, pH, and moisture), exposure and other microclimatic factors, i.e., elevation.

These factors will allow specific seed mixtures to be recommended using adapted varieties and secondary cultivars in specific proportions.

Commercial availability of native cultivars will always be a factor in developing recommendations.

The seed industry in Alaska is still in its infancy, and a degree of reluctance to grow new cultivars still exists in the commercial sector.

Willow Planting Techniques

Of all the methods used in Alaskan reclamation, willow planting is, by far, the most maligned. The

Table 1. Adaptability of Species/Cultivars Tested.

Species/Cultivar	Regions						
	Arctic	Western Alaska	Interior	South Western	South West Alpine	South Central	South East
Kentucky Bluegrass							No evaluation by the Plant Materials Center has occurred in Southeast Alaska as of 1988.
Nugget	2	1	1	1		1	
Merion		2	2	1		2	
Sydsport		2	2			2	
Fylking			2	2		2	
Park			1			2	
Red Fescue							
Arctared	1	1	1	2	1	1	
Boreal		1	1	1	1	1	
Pennlawn				1		1	
Alpine Bluegrass							
Gruening	1		1		1	1	
Glaucous Bluegrass							
Tundra	1	1	1				
Polargrass							
Alyeska	1	1				1	
Bering Hairgrass							
Norcoast	2	1	1	1	1	1	
Bluejoint							
Sourdough	2	1	1	1	1	1	
Sloughgrass							
Egan	1	1	1			1	
Brome							
Polar		1	1			1	
Manchar		2	1			1	
Sheep Fescue							
Highlight		2				2	
Reed Canarygrass							
Vantage		2		1			
Timothy							
Engmo			1			1	
Meadow Foxtail			2	2		2	
* Violet Wheatgrass	2		2				
* Rough Fescue		2	2	2		2	
* Tilesy Sage		2	2	2		2	
* Big Bluegrass		2	2				
* Beach Wildrye		2		2			
* Boreal Wheatgrass			2				

* Those species so noted have not been released by the Plant Materials Center, and are therefore listed as secondary choices (2). After release, many of these will become preferred choices (1).

only large-scale use of willow by industry has been the plantings conducted on the Trans Alaska Pipeline. A decade has past since this attempt and methods have improved.

In 1979, the PMC started investigating improved methods to establish willow. These methods not only needed to produce a high degree of success, but also needed to be cost-effective.

The Plant Materials Center started with 8-10 inch dormant, unrooted cuttings. This method has proven successful, provided grass competition is not significant and adequate moisture is available. Dormant, unrooted cuttings provide the advantage of being easy to prepare and plant as well as being low in cost.

The disadvantages of this method are: 1) the cuttings must be kept in cold storage until planted, 2) they must not be permitted to dry out or become excessively wet during storage, 3) they have a lower survival rate than other methods, and 4) it requires planting sites with adequate soil moisture.

The next method that was adopted by the PMC, was bundling or wattling of dormant material. This technique involved tying four-foot long, dormant willow branches in bundles 4-6 inches in diameter. The bundles are then planted horizontally to a depth three fourths of the bundle's diameter. This method has proven to be more able to compete with grass. The prime advantage to this technique is the physical block that the bundle mass provides in erosion control. Bundles also provide quick linear cover.

The disadvantages are the same as for dormant cuttings except soil moisture is not as critical. This method does require more plant material than any other method.

The use of container grown cuttings is probably the most effective method to establish willow. It is more costly than using dormant material, and also requires more care in planting.

The advantages are obvious. The plants are established and growing when planted. The container material is also more suited to dry sites. The age of the planting stock can range from material rooted in the year of planting to 1-0 and older stock (Moore et. al. 1986, Wright and Moore 1986).

More efficient methods of planting need to be developed before large-scale plantings are likely in Alaska. This is presently being explored by the Plant Materials Center.

Dormant Seeding vs. Traditional Spring Seedings

The Center is actively attempting to determine if dormant seeding is a viable procedure in Alaska. Because of Alaska's long winters, heavy snowfall, and rapid melt, it has been the feeling of many in Alaska that dormant seedings are not practical. Therefore, most seedings are conducted between May and July.

By permitting dormant seedings, the period to seed would be greatly increased. This would, of course, allow greater flexibility in scheduling revegetation. Seedings in the Arctic can be restricted to a period as short as 20-30 days.

Recent findings by the Plant Materials Center at the Kuparuk Oil field, Red Dog Mine and the Beluga Coal fields, have suggested that dormant seedings are possible. The critical factors in dormant seedings are still slope and spring run-off. On level ground, as was used in the plots, no difference in overall success was noted between dormant and non dormant. However, in the Kuparuk plots, prolonged dormancy in some of the spring seeded grasses occurred. In fact, some accessions did not break dormancy for one year. The dormant seedings produced measurable stands the spring following planting. A slight increase in vigor was noted for the dormant seedings (Wright 1986c, 1987e, 1989a, b).

Wetland Revegetation and Restoration

The importance of wetlands in Alaska cannot be understated. In addition to the ecological importance of these areas the regulations developed to protect them can be overwhelming.

The Plant Materials Center is the only agency in State government attempting to solve problems associated with revegetation of wetlands.

The Center has worked with the Alaska Department of Fish and Game and Ducks Unlimited in the revegetation of two waterfowl habitat enhancement projects. These projects, at Palmer and Fairbanks, have demonstrated the effectiveness of new wetland cultivars developed in Alaska; primarily 'Egan' american sloughgrass and 'Norcoast' bering hairgrass.

Another demonstration project that was designed to revegetate a wetland area was the Bethel Small Boat Harbor. This project, initiated in 1984 in cooperation with the Corps of Engineers, proved the adaptability of 'Egan' american sloughgrass and 'Norcoast' bering hairgrass to the Bethel region of western Alaska and the adaptability of these species for wetland reclamation (Moore 1986).

Presently, the Plant Materials Center, in cooperation with ARCO Alaska, is attempting to determine the potential of successfully establishing arctic pendant grass, Arctophila fulva, in the Arctic. Arctic pendant grass is an emergent species usually associated with lakes and ponds in the Arctic.

Initial findings, after four years of investigations, have been inconclusive as to success and economic feasibility of transplanting arctic pendant grass (Moore and Wright, in press).

Coastal Restoration and Erosion Control

Alaska has more coastal shoreline than the remainder of the United States combined. Therefore, coastal revegetation merits study.

The first major project involving coastal revegetation and erosion control in Alaska occurred on Shemya Air Force Base. The base is located approximately 1,500 air miles south of Anchorage, on Shemya Island in the last group of islands at the western extreme of the Aleutian Island chain. Shemya Island is roughly four miles east to west and two miles north to south.

Climatically, the island is classified as maritime. Seasonal variations in temperature are small. Mean daily temperatures in January are approximately 31° F, and in July they are approximately 45° F. Average annual precipitation is slightly less than 28 inches. The most obvious and overriding climatic factor is wind and fog. Severe winds, at times in excess of 70 knots, can lash the island. The most significant winds occur during late fall, winter and early spring.

In 1987, construction adjacent to the runway at Shemya Air Force Base, removed existing dunes and vegetation and exposed 27 acres of erodable sand to the winds. Transported sand would cause aircraft maintenance and safety problems.

Previous attempts to revegetate the area adjacent to the runway failed. In 1987, the U. S. Army Corps of Engineers Alaska District and the PMC designed a revegetation and erosion control project to prevent erosion on the area planned for construction in 1987.

Based on initial studies in 1986, it was determined that beach wildrye, Elymus arenarius L. (also referred to as E. mollis Trin.) could be established using transplanted sprigs (Wright 1986d).

The revegetation plan also called for seeding with the adapted perennial grass 'Norcoast' bering hairgrass. Adapted cultivars of red fescue and traces of annual ryegrass were also indicated.

The seed mix was applied at a rate of 60 pounds per acre.

Prior to sprigging, the area was fertilized at a rate of 500 pounds per acre of 14-30-14. A supplemental application of 75 pounds per acre of 34-0-0 occurred 60 days after seeding.

In May, 1987, the contractor, aided by the Center, started the revegetation project. Minor modifications to the available construction equipment allowed the methods for harvest and planting to be simplified to the point where the rate for planting one acre (20,000 sprigs) was 60 man hours.

In September, 1987, the area was evaluated. Twelve 50-meter transects indicated that 90% of the beach wildrye sprigs had become established.

Overall ground cover was 80-85%, 41% of which was beach wildrye, 43% seeded perennial grasses, 15% annual ryegrass, and <1% invading native broadleaf species. The vigor of the vegetation was good to excellent (Wright, et. al. 1987).

Stand diversity was higher than expected. Propagules from broadleaf native species had been introduced when a thin (2-4 inches) veneer of peat had been applied to the area as a temporary solution to reduce wind erosion.

The project was the first major attempt to establish beach wildrye in Alaska. The success of the project indicates that it is a viable reclamation and erosion control method.

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HOLLOW FILL CONSTRUCTION AT THE AMOS RIDGE EXPERIMENTAL PRACTICE[1]

Carl E. Zipper and W. Lee Daniels[2]

Abstract: Between January, 1984, and October, 1988, the Amos Ridge Coal Company performed contour surface mining operations in steeply-sloping terrain under an experimental practice variance from the requirements of SMCRA, as implemented by the Virginia Coal Surface Mining Regulations. The objective of the experimental practice was to investigate the feasibility of experimental spoil handling practices. All environmental performance standards of SMCRA were met, with the exception of those regulations dealing with the construction of hollow fills and the restoration of approximate original contour. Three different hollow fill construction methods were used; one conforming to OSMRE and Virginia regulations, and two using experimental techniques. An intensive data collection program documented economic, operational, and environmental consequences of the mining and reclamation procedures utilized. The results indicate that spoil was handled in cost-effective and environmentally sound fashion, in spite of departure from procedures specified by SMCRA. Analysis of costs of constructing hollow fills indicate distinct differences in the per-cubic-yard costs of spoil disposal among the three fill designs utilized. An experimental hollow fill design, using a rock core chimney drain, appeared to be more cost effective than either of the other two fill designs. However, elapsed time since completion of the fills is not sufficient to compare long-term environmental impacts.

Additional Key Words: Surface Mining Control and Reclamation Act, Excess Spoil Disposal, Reclamation Costs, Steep-slope mining.

Introduction

The Amos Ridge Coal Company performed contour surface mining operations in a steeply-sloping section of Wise County, Virginia, over a period extending from the 1960s to the late 1980s. Between January, 1984, and October, 1988, mining operations were conducted under a permit specifying an experimental practice variance from the requirements of the Surface Mining Control and Reclamation Act (SMCRA).

The purpose of the experimental practice was to investigate the feasibility of spoil handling practices other than those required by SMCRA and the Virginia Coal Surface Mining Regulations implementing SMCRA. The practices investigated were alternatives to standard hollow fill construction techniques and the restoration of approximate orginal contour. The post-mining landform includes a large flat bench area, extending over the three hollow fills and the adjacent points which were not restored to their original heights after mining. The upper surface of this bench area was constructed using a thick layer of uncompacted soil and spoil materials, selected and placed to maximize plant growth potential. The resultant landform is suitable for a wider variety of economically-valued land uses than the steeply-sloping premining topography.

The purpose of this report is to summarize the results of observations and analyses at the experimental practice mining site over the 1984 - 1988 period, with special emphasis on those results comparing the costs of hollow fill construction. Personnel from Virginia Polytechnic Institute and State University, representing the Powell River Project, monitored mining and reclamation operations at Amos Ridge throughout the experimental practice period.

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The Experimental Practice

The experimental practice variance was obtained in accordance with the requirements of Section 711 of SMCRA, with the cooperation of the Virginia Division of Mined Land Reclamation and the U.S. Office of Surface Mining Reclamation and Enforcement. The objectives of the experimental practice as stated in the permit application were to:

1. investigate the economic and engineering feasibility of constructing excess spoil fills using alternatives to procedures specified in the then-current Virginia Coal Surface Mining Regulations.
2. determine the long run impacts of this and similar practices on the environment and the southwest Virginia coal industry.
3. produce a carefully constructed surface mined area of higher land use value for use in the ongoing reclamation research program of the Powell River Project.

There were two distinct components to the experimental spoil handling procedures employed in reclaiming the mining site; both were essential to the ultimate result: a stable, environmentally-sound landform with an improved land use potential, relative to the steeply-sloping pre-mining landform (Fig. 1).

Experimental hollow fill construction procedures were employed at the Amos Ridge mining site. A major purpose of the experimental practice was to determine the feasibility of using construction techniques other than those specified in Virginia Coal Surface Mining Regulations V816.71 (which corresponds to federal regulations 30CFR 816.71) for the disposal of excess spoil. In carrying out this experiment, one excess spoil fill was constructed using standard design practices, and two fills were constructed using experimental techniques.

The mining operation also was conducted with a variance from the "approximate original contour" (AOC) provisions of SMCRA. This variance was obtained by meeting the requirements of Section 515(e) of SMCRA. Variance from AOC was an essential component of the experimental mining method investigated at Amos Ridge, where the pre-mining topography consisted of a series of finger ridges protruding from the central "spine" of Amos Ridge. This type of topography is common throughout central Appalachia. Excepting the tops of the fingers, nearly all the land being mined slopes in excess of 20 degrees. Thus, the Amos Ridge mining operation constitutes steep slope mining as defined by SMCRA.

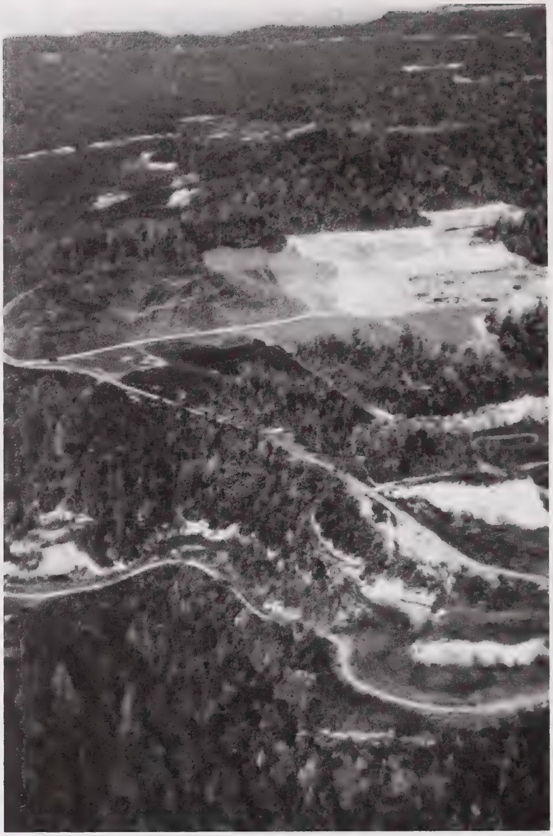

Figure 1. An aerial photograph of the Amos Ridge site in October, 1987. Active mining is shown on the right side of the photo; reclaimed areas are located left of the active mining area. The outslopes of HF1 and HF2 are visible in the reclaimed area; HF3 was under construction at this time. Exposed highwalls above and below the mining site are the result of pre-1977 mining. Experimental plots are visible on the level bench area to the immediate left of HF1.

Contour mining was conducted across four finger ridges and three intervening hollows while removing three seams of coal (the Low Splint seam, and its Upper and Lower Markers) running through the upper fraction of these ridges. Rather than completely rebuild the finger ridges to their approximate original contours, the firm used spoil generated from the finger ridges to construct three hollow fills. The result is a relatively large near-level "bench" (approximately 12 of the 72 acres under permit), a terrace-like landform extending over the stripped fingers and filled hollows. The objective of producing a usable, stable landform was pursued by constructing the hollow fill outslopes at

3:1 grades (rather than the maximum-allowable 2:1 [30CFR 816.71]) and by building plant growth media with selected, uncompacted soil and spoil materials. All highwalls were backfilled. With the exception of the AOC and hollow fill construction provisions, all SMCRA performance standards and Virginia regulatory standards were met.

Economic, environmental, and regulatory implications of the AOC variance have been summarized elsewhere (Daniels et al., 1989; Zipper et al., 1985, 1988, 1989a, 1989b). The primary purpose of this manuscript is to review results of monitoring hollow fill construction.

Data Collection

Over the January 1, 1984 - April 15, 1988 period, the mining site was visited at least one day per month. Four additional site visits were made, for data collection purposes, in May, July, and August, 1988, and in October, 1988, when reclamation had been totally completed. During these visits to the site, a variety of data were collected.

Photographs (35mm slides) were taken each month. These photos were numbered, described, and submitted to OSMRE with monthly reports. Many of the photos were taken from pre-defined "photo points", locations on the landscape providing an excellent view of one or more areas of mining operations. The month-by-month sequences of photos taken from these points provide a visual record of mining operations.

Daily records of machinery operation and mining progress were maintained by the operator on forms provided specifically for this purpose. During each site visit, a package of completed forms was picked up and a fresh package delivered. All operations lasting 20 minutes or longer were recorded on the forms. The data forms were supplemented with a site map on which the mining operator used symbols to depict mining operations. Data were kept continuously in this fashion over the entire 1984-1988 period. Locations were specified with reference to mining blocks, which were defined and numbered as appropriate at the site.

Hauler load counts were maintained by the hauler drivers between August, 1984 and April, 1988. Each hauler was outfitted with pencils, a clipboard, a calendar, and a hand-operated counter. The drivers were asked to count and record the number of loads hauled each day. Marked calendars were retrieved and replaced during monthly visits.

Selected site measurements were taken during the most intensive period of observation, between January, 1984, and August, 1985. The objective of these measurements was to accurately estimate overburden volumes.

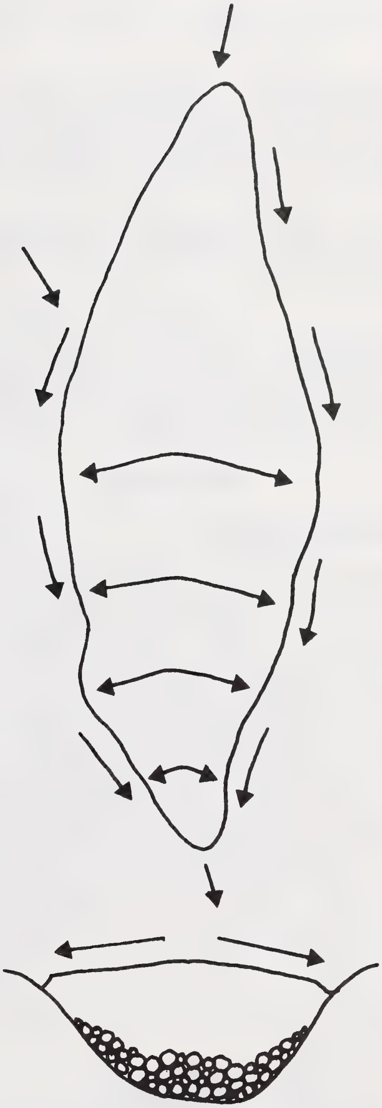

Figure 2. Plan and cross-section drawings of Hollow Fill 1. Drawings are not to scale. Arrows indicate directions of surface drainage flow.

Data on unit operations were also recorded, as appropriate. Operations timed and measured included blasthole drilling rates, and overburden movement by dozers, loaders, and haulers. Again, these data were recorded during the 1984-1985 period.

Observations on mining progress were recorded. Mining progress was discussed with the operator. These observations were summarized and recorded in the inspection reports submitted to OSMRE.

Pneumatic piezometers were installed in the base of the hollow fills, to determine subsurface pore pressures.

Water quality data were collected by Amos Ridge Mining Co. as required by the Virginia Coal Surface Mining Reclamation Regulations. Four sampling points were defined, including the outflows of the three hollow fills.

The Hollow Fills

Construction Procedures

Hollow Fill 1 (HF1) was constructed as a conventional durable rock fill (Fig. 2), as described in Virginia Coal Surface Mining Reclamation Regulation V816.73. These regulations correspond to federal regulations 30CFR 816.73. The total fill contains greater than 80% durable rock. Segregation of spoil at the mining pit was practiced throughout the fill construction period in order to acheive this 80% durable rock standard. The fill was end dumped in lifts approximately 50 to 75 feet in thickness. A blanket drain was constructed by segregating large, durable rocks and by placing these rocks into the fill using end dumping procedures during construction of the bottom lift. The outslope was constructed at a 3:1 grade, with terraces at 50 foot vertical intervals. The outslope was crowned, to lead water to the surface drains at either edge. Surface runoff from the landscape above was directed to the diversion adjacent to the fill's north face.

Hollow Fill 2 (HF2) and Hollow Fill 3 (HF3) were both permitted for construction using experimental procedures. Both were permitted for less than 80% durable rock, with the minimum durable rock content specified at 50% to 55% respectively. Both fills were permitted as variances to the V816.73 durable rock fill construction standards.

Hollow fill 2 was constructed using a rock core chimney drain (Fig. 3) This drain was constructed according the standards of V816.72(b), which defines procedures for rock-core chimney drains in fills with volumes less than 250,000 cubic yards, although the fill's design volume was in excess this maximum capacity. Also, surface drainage water from the fill itself, and from the watershed above, is diverted through the chimney drain, rather than around the fill as is normally required by V816.73(f). Thus, the chimney drain system is dual purpose, serving as an internal drainage system and to carry surface drainage. The outslope was constructed at a 3:1 grade, with terraces at 50 foot vertical intervals. The outslope was not crowned; rather, terraces drain to the outcrop of the chimney drain, at the east-west center line of the fill.

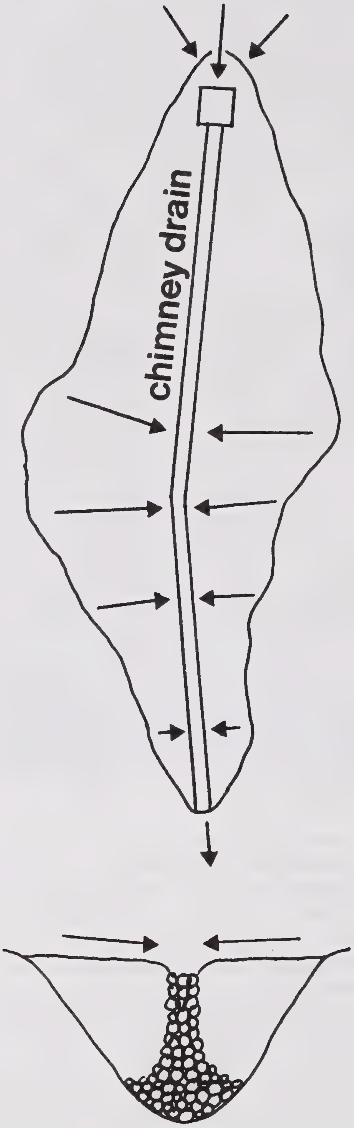

Figure 3. Plan and cross-section drawings of Hollow Fill 2.

In order to achieve this result, the fill was constructed in three lifts, each 50 to 75 feet in thickness. Spoil was placed in the fill by dumping from the fill sides towards the center. As the spoil disposal began to approach the fill center, during construction of each of the three lifts, durable rock was segregated at the mining pit and placed via standard side-dumping procedures. The result was a substantial drainage system, with dimensions far exceeding the 16 foot minimum thickness requirement of V816.72(b), constructed with a minimum of special handling.

Hollow fill 3 was constructed using a filtered underdrain system as defined in V816.71(f) and V816.72(a) (Fig. 4). This drain was constructed as a bed of durable rock boulders, covered by filter fabric and a layer of sandstone fines (Fig. 5). The fill body was constructed using end dumping techniques, in lifts 50 to 75 feet in thickness. The outslope was constructed at a 3:1 grade, with a slight crown to divert surface waters from the face to the diversions constructed at either edge of the face. Surface waters from the landscape above are diverted around the fill, into the rock-lined drainage channel constructed on the fill's north side.

Virginia regulations defining hollow fill construction procedures have been modified during the course of the experimental practice. In the above narrative, we have referred to regulatory statutes using the current numbering system, rather than the outdated system found in the original permit. A consequence of regulatory change is that HF3 is no longer experimental. Recent changes in the Virginia system allow non-durable rock hollow fills to be constructed in lifts greater than four feet in thickness, if a minimum factor of safety is met. Due to the favorable characteristics of the site and the 3:1 hollow fill outslope gradient, these standards are achieved by the third hollow fill. Therefore, HF3 meets current regulatory standards in spite of being initiated as an experimental fill.

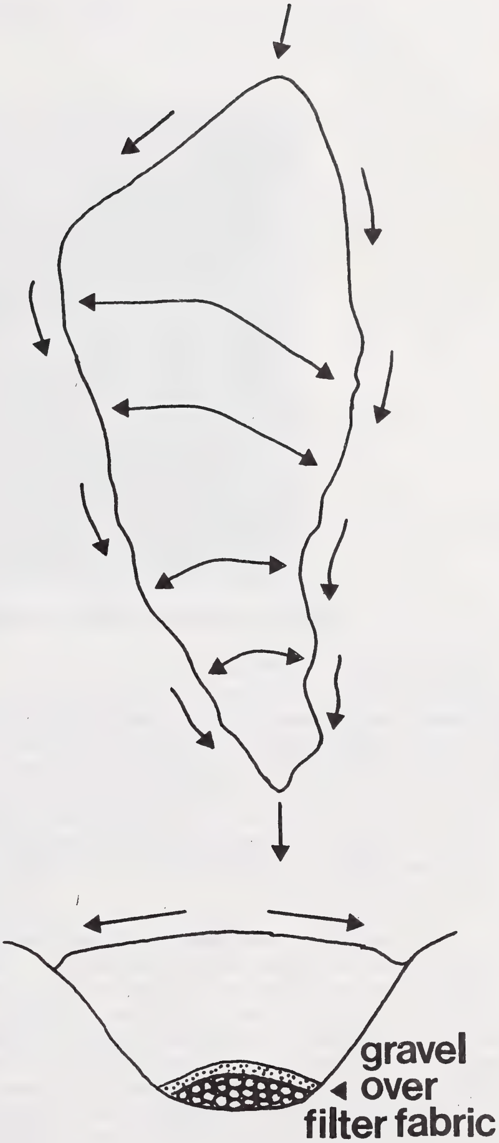

Figure 4. Plan and cross-section drawings of Hollow Fill 3.

Differences Among the Fills

Aside from the essential differences among fill designs, there were other differences among the procedures used to complete the three hollow fills which influenced costs (Table 1).

Topsoil was removed from the first hollow prior to fill construction. Since this proved to be a costly and time-consuming operation, a variance from the topsoil removal requirement was sought and obtained for the second and third hollows. Due to hollow configurations, fill stability does not seem to be a problem with topsoil in place. The widespread availability, and permit approval for use of, topsoil substitute materials eliminates the necessity to remove topsoil for revegetation purposes. Nonetheless, large quantitities of topsoil were removed from easily-accessible areas of the second and third hollows, in order to aid revegetation of reclaimed areas.

Substantial reworking of materials dumped into all three fills was required in order to achieve the 3:1 outslope gradient, since 3:1 is less steep

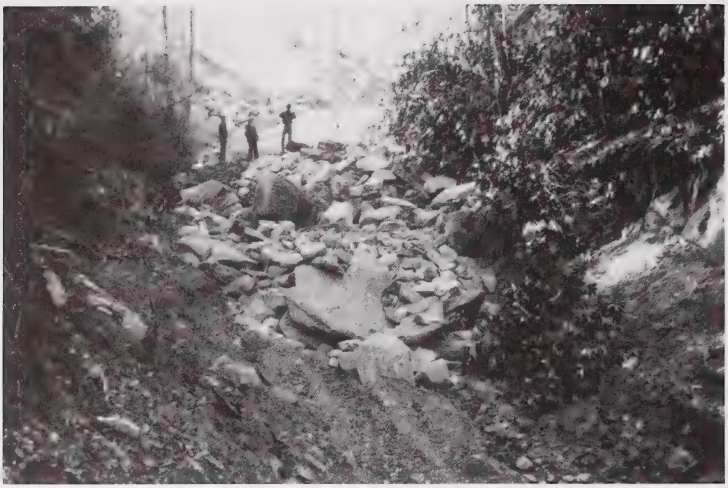

Figure 5. Underdrain of HF3 during construction in December, 1986.

than the angle of repose of the sandstones and siltstones spoils used for fill construction. This procedure proved to be most difficult and costly in HF1, since this fill was constructed of greater than 80% durable rock. The operator had far more latitude in selecting materials for the second and third hollow fills. Thus, he was able to place softer, more easily worked, spoil materials in the outslope zone of these two hollow fills.

Due to unanticipated coal marketing problems, HF3 construction was halted prematurely. However, the design standards defined in the permit application were followed during reclamation and drainage channel construction. Inability to complete the fill as planned was the cause of the decision to rehandle spoil to complete HF3 (Table 2). This procedure was employed in order to blend the configuration of HF3 in with that of the surrounding landscape. Had mining been able to proceed as originally planned, this rehandling of spoil would not have occurred.

Estimating Costs and Volumes

Expenses required to complete the hollow fills are calculated on the basis of the number of man hours and machine hours expended to perform hollow fill related operations, as recorded in the Daily Record of Machine Operations. Machinery hours spent moving material from the mining blocks to the hollow fills were not considered as a cost of hollow fill construction. Rather, these were considered as direct costs of mining coal from the blocks indicated. Similarly, the cost of moving topsoil to hollow fills for reclamation purposes is not included in the operation and cost summaries. The costs of the hollow fills include all machine and man hours spent preparing the hollows for material placement, working material after placement as per design and reclamation requirements, and preparing the surface materials for revegetation. The method used to develop hourly cost estimates for machinery operation is detailed by Zipper et al. (1985).

The estimate of the volume of materials placed in HF1 is based upon counts of the number of hauler loads placed in the fill, the number of hours spent carrying and pushing from each source area into the fills, and the volume estimates of the source blocks which were developed from on-site measurements. Based upon the estimated block volume and the total number of hauler loads and machinery hours required to completely remove all spoil from each source block, the quantity of materials removed from each block to each disposal area (including HF1) was estimated. After August of 1985, no measurements of source blocks were performed, and no estimates of source block volumes were developed. Subsequent volume estimates (HF2 and HF3) are based upon per-hour and per-hauler-load movement rate estimates which were developed during the source block measurement period over 1984 and 1985 (Zipper 1988).

Table 1. Comparison of hollow fill characteristics.

Characteristic	HF1	HF2	HF3
Topsoil removal required	yes	no	no
Durable rock content	>80%	50%-80%	50%-80%
Drainage:			
Internal	blanket	chimney	underdrain
Fill surface	side	center	side
Watershed above	around	through	around
Outslope gradient	3:1	3:1	3:1
Filled to design capacity	yes	yes	no
Meets 1984 regulatory standards	yes	no	no
Meets current regulatory standards	yes	no	yes

The loose cubic yard (lcy) figures reported in Table 2 should be considered as approximate, showing greater accuracy in a relative than an absolute sense. Accurate estimates of spoil movement volumes during surface mining operations are extremely difficult to prepare. Difficulties include estimating undisturbed volumes of source blocks, estimating swell factors, apportioning a spoil movement among disposal areas on days when material segregation is practiced, and apportioning disposed spoil among adjacent disposal areas when the disposal point is close to the disposal area boundary.

Comparing Fill Construction Costs

Table 2 summarizes hollow fill costs and volumes. There was a remarkable consistency among the total costs to complete each of the three fills, given the diversity of terrain and construction

Table 2. Comparison of hollow fill costs and volumes.

Volumes and Costs	HF1	HF2	HF3
Volumes (lcy):			
Design	280,000	350,000	240,000
Estimated	197,255	227,029	160,971
Operational Costs:			
Prepare hollow	$9,379	$12,333	$9,469
Construct fill	$9,649	$9,343	$11,415
Reclamation	$9,749	$8,078	$7,461
Rehandle spoil			$3,490
Total costs	$28,777	$29,754	$31,835
Total costs per lcy disposed:			
Design volume:	$.103	$.085	$.133
Estimated volume:	$.146	$.131	$.198
Costs exclusive of rehandle spoil:			
Total	$28,777	$29,754	$28,345
Per lcy: design volume	$.103	$.085	$.118
Per lcy: estimated volume	$.146	$.131	$.176
Costs, fill construction and reclamation only:			
Total	$19398	$17421	$18876
Per lcy: design volume	$.069	$.050	$.079
Per lcy: estimated volume	$.098	$.077	$.117

methods, especially if the cost of rehandling spoil to complete HF3 is eliminated from the comparison. However, a more detailed look at cost figures shows distinct differences among the costs of the various operations required to completely build and reclaim the three fills.

Three major cost categories were used to calculate hollow fill spoil disposal costs. The cost of hollow preparation includes operations required to gain initial access to the fill, clearing trees and vegetation from the hollow sides, and removal of topsoil as required for fill stability and to provide a solid base for drainage structures. HF2 was substantially more expensive to prepare than HF1 or HF3, due to the steepness of the hollow sides. A large amount of hand work was required to remove vegetation from the hollow, including manual removal of trees and stumps with a dozer and chain. In the other two hollows, these operations were accompished more efficiently.

The construction cost category includes internal and surface drainage construction and reconfiguration of the fill body to achieve a 3:1 outslope gradient. Two major factors help to explain construction cost differences among the fills. As discussed above, reconfiguration of HF1 materials to achieve the 3:1 outslope gradient was a costly procedure. However, this cost was balanced, in large part, by the ease of internal drain construction which occurred as an integral component of the spoil disposal process. The construction cost of HF3 was the largest of the three fills, primarily due to the high cost of the rock underdrain. This drain design required far more special handling of materials than either of the other two drainage systems even though the total amount of rock involved was less. The cost of operations required to construct the HF3 drain is estimated at $8400. The cost of grading fill materials to a 3:1 gradient was actually the lowest for HF3, due to its reduced volume and the placement of external drainage channels along the fill sides, rather than in the center as in HF2.

The reclamation cost category includes surface grading and seeding. The reclamation cost for HF1 was greater than the corresponding cost for HF2 or HF3. The higher reclamation cost of HF1 was primarily a result of increased grading requirements, due to the establishment a pronounced crown on the fill face and to the detailed grading required to establish surface drainage at the head of the fill.

On a per loose cubic yard of spoil disposed (per lcy) basis, HF2 was the least costly of the three fills, while HF3 was most clostly. This per-lcy cost difference is amplified if preparation of the hollows is eliminated from the comparison, since cost differences within this category result primarily from hollow configuration rather than fill design.

Because the total costs of all three fills are so similar, it is difficult to draw a firm conclusion that the HF2 design is clearly superior to the other two designs, from a cost standpoint. A major cost of HF1 -- reconfiguration of spoil to a 3:1 gradient -- was an outgrowth of the experimental practice procedure. Had a more conventional (i.e. steeper) outslope gradient been employed, HF1 would not have suffered this particular cost disadvantage relative to the other two designs. Differences in hollow configurations, and in various aspects of mining operations among the periods when the the three fills were being constructed, make it difficult to conclude that the HF2 design is clearly more cost effective. Similarly, had the the other two hollows been filled to the volume of HF2, the cost of hollow fill operations may not have increased in direct proportion to volume which would have reduced per-lcy cost differences among the three fill designs.

Nonetheless, from an operational standpoint, there are clear differences among the fills which are not reflected in the cost figures and which cause HF2 to be considered as superior to the other two designs.

HF3 was the most costly of the three fills, due primarily to the direct cost of establishing the underdrain. There is also a major disadvantage to HF3 from an operational standpoint: the entire drain must be constructed before filling of the hollow can be initiated. The drain runs down the center of the hollow, the precise location where operations are most likely to be disrupted in the event of wet weather. This requirement to install the drain before initiating spoil disposal can act as a major constraint on mining operations. In both HF1 and HF2, drains were constructed as integral components of spoil disposal processes (Fig. 6).

In comparison with HF1, the obvious advantage of the HF2 design is the reduced quantity of durable rock that is required. Although durable rock segregation was not calculated as a cost of hollow fill construction in this analysis, it can be a very real cost of operations where durable rock is limited in quantity. Not so obvious is the difference in costs of handling surface drainage. The HF1 design requires that surface drainage channels be constructed down either side of the fill outslope, and that the surface drainage from the watershed above be diverted around the fill. Surface drainage is handled in more cost-effective fashion in HF2 where only one channel is required (up and down the center face of the fill). Watershed drainage is allowed to enter a basin at the head of the fill, and to

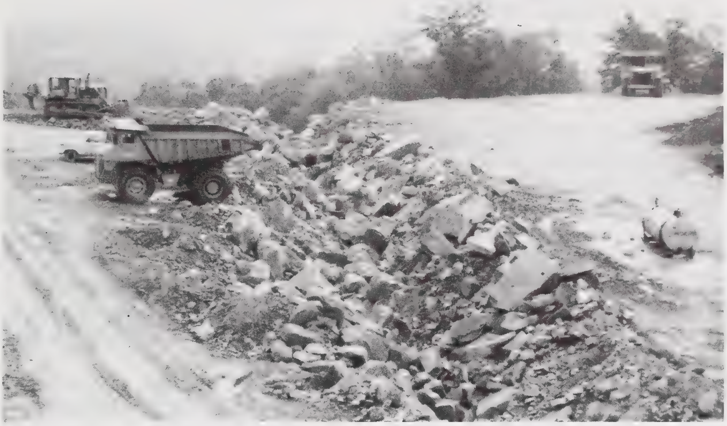

Figure 6. Upper surface of HF2 during the final stage of fill construction, prior to reclamation.

pass through the chimney drain to emerge at the fill's toe.

Non-cost Fill Comparisons

Land Use: One difference that does not show up in Table 2 is the effect of surface drainage structures on land use. From a land use standpoint, the "double" surface drain requirements of HF1 and HF3 limit the operator's ability to tie the topside of the hollow fill surface into the adjacent stripped points to create a more continuous landform. The final, upper surface is dissected on both sides of HF1 and HF3, as these designs require surface drainage structures to be constructed on both the north and south edges of each fill. In contrast, HF2 only has one surface drainage system, which runs through and over the the center line of the fill and the hollow. This situation more closely resembles the natural terrain, allows the upper surface of HF2 to be tied more directly to the stripped points, and requires that less surface area be occupied by surface drainage structures.

Internal drainage: In spite of the differences in fill designs, field operations caused the basal portions of HF1 and HF2 to be quite similar. In both fills, the first stage of fill construction was to dump a lower lift of durable rock. In both cases, large, durable rocks tended to roll from the dumpsite to segregate at the base of the filled materials, covering the terrain underlying the fills. Also in both cases, the thickness of this durable rock base tended to be greatest at the hollow center. The cross-sectional areas of the drainage structures at the base of HF1 and HF2 appeared to exceed that of HF3, and far exceed the minimum underdrain cross sectional area defined by V816.72 and the corresponding federal regulation. A logical conclusion would seem to be that these drains, with larger cross-sectional areas, would be less vulnerable to clogging or other disruptions of function.

Environmental: Piezometer readings taken thus far indicate no drainage problem with any of the fills (Zipper 1988). Although elapsed time has been insufficient to draw any conclusions regarding long-term fill stability, all fills are currently draining freely. In fact, based upon the piezometer readings, it is difficult to discriminate summer from winter. Large, hard sandstone boulders were used to construct the drains in all three fills. All three drains were oversized, relative to permit specifications.

Similarly, there has been no problem with the drainage from any of the fills, in terms of water quality. No treatment of drainage has been required to meet water quality standards.

Conclusions

Research conducted at the Amos Ridge Experimental Practice over the 1984-88 period indicates that the spoil handling procedures utilized provide substantial benefits relative to standard AOC practices at this site. The advantages of the method utilized at Amos Ridge, in comparison to AOC, include a more stable landform, enhanced land use potential, increased coal recovery, and decreased spoil handling costs (Bell et al. 1989; Zipper et al. 1985, 1988, 1989a, 1989b). The experience gained at Amos Ridge indicates that spoil can be handled in cost effective and environmentally sound fashion, in spite of departing from standard AOC practices.

The ability to construct cost effective, environmentally sound hollow fills is essential to the ability of mining firms to produce reclaimed lands with enhanced use potentials: flat lands that will serve as assets to the communities of central Appalachia. The results reported here indicate that the most cost effective fill design utilized at Amos Ridge is the design which does not conform to current regulatory requirements. To this date, this experimental fill has shown no signs of being any less environmentally sound than either of the other two fills. However, insufficient time has passed to judge the long term environmental impact of this currently experimental hollow fill design.

Acknowledgements

The authors wish to acknowledge support and assistance received from the Powell River Project and Amos Ridge Coal Company, which made this research possible. Additional financial support was provided by the U.S.D.I. Office of Surface Mining Reclamation and Enforcement; the U.S.D.I. Bureau of Mines Mineral Institute Program, grant G1144151; and the Virginia Center for Coal and Energy Research. Assistance was also provided by the Virginia Division of Mined Land Reclamation, Penn Virginia Resources Corporation, and Westmoreland Coal Company.

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MOOSE AND DEER HABITAT USE AND DIET ON A RECLAIMED MINE IN WEST-CENTRAL ALBERTA

by

Nicholas A. Roe[2] and Alan J. Kennedy[2]

Abstract. Moose(*Alces alces*) and deer (*Odocoileus* spp.) use of a reclaimed coal test mine site and adjacent habitat in west-central Alberta was monitored to determine habitat use, use of planted shrubs, and diets. In 1979, the site was seeded with grasses, alfalfa(*Medicago sativa*) and clover(*Trifolium* sp.), then planted with lodgepole pine(*Pinus contorta*) and white spruce(*Picea glauca*) seedlings, and willow (*Salix pedicularis*). Mean levels of use by moose and deer of the site were higher than in adjacent habitat, not significantly by moose ($p>0.05$), significantly by deer($0.05<p<0.10$). Use of the site was variable from year to year, with no clear trend; variability was less in adjacent habitats. Days-of-use/ha of the site by deer was twice that of moose, but the difference was not significant on a year-by-year basis. Moose diet was primarily willow(88%) and spruce(8%); deer diet was primarily *Cornus* (31%), legumes(23%), *Equisetum*(15%), and *Populus*(6%). Planted willow shrubs were heavily or moderately browsed between 1981 and 1985. Seeded grasses were sparingly grazed.

Additional Key Words: Western Canada; reclamation; willows; ungulates.

Introduction

In the mountain and foothills biomes of Alberta, mining exploration and extraction have resulted in removal of forest cover and disturbance of a moderate amount of land(Thirgood and Ziemkiewicz 1978, Marshall 1983). Although the removal of forest cover can improve habitat for some wildlife species through the creation of ecotones, physical land disturbance may reduce the local availability and

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quality of wildlife habitat (Alberta Energy and Natural Resources 1984). We report on a monitoring study which quantified the use of reclaimed mine land by deer and moose in west-central Alberta, and documented the efficacy of the new wild ungulate habitat provided.

Recent studies of wildlife habitat and mining in Alberta have been directed towards determining habitat requirements (Green *et al.* 1986, Green and Salter 1987) and documenting procedures to establish wildlife habitat on abandoned mining areas(Green *et al.* 1986). Published studies of wild ungulate use of reclaimed mines in western Canada either focus on elk (*Cervus elaphus*)(Kuhn and Martens 1980), or do not distinguish between ungulate species (Stanlake *et al.* 1978). The following study focuses on deer and moose, and is set at a more northerly latitude than other published Canadian studies.

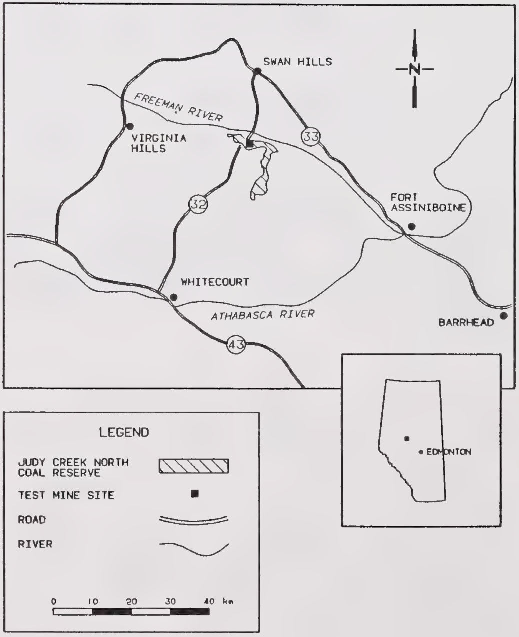
During January, 1979, Esso Resources Canada Limited excavated a coal test mine to obtain a bulk sample from the Judy Creek North reserve. A subsequent program to stabilize and reforest the test mine site, in conjunction with a vegetation and wildlife monitoring study, provided the opportunity to evaluate use of the habitat by moose and deer. Mule deer(*Odocoileus hemionus*), white-tailed deer(*O. virginianus*) and elk occur in the region; however, white-tailed deer appear to be much less abundant than mule deer, and elk have been recorded only occasionally. The specific objectives of the study were: (1) to determine moose and deer habitat utilization on the test mine site and surrounding habitats; (2) to evaluate the use of planted deciduous shrubs on the reclaimed area; and (3) to document moose and deer food habits.

The Study Area

The Judy Creek test mine site is located at an elevation of 980 m above sea level, 53 km southwest of Swan Hills, Alberta(Figure 1). The mean annual temperature is 4°C. Mean annual precipitation is 42 cm, and most occurs during the growing season.

The test mine site is approximately 18 ha in area. The area adjacent to the test

Figure 1.
Location of the Test Mine Site



mine site supports primarily coniferous and mixedwood forest communities. Dominant forest cover types are: lodgepole pine-black spruce(Picea mariana)/ feathermoss; trembling aspen(Populus tremuloides)-white spruce/low bush cranberry(Viburnum edule); lodgepole pine/ bunchberry (Cornus canadensis)-bog cranberry (Vaccinium vitis-idaea); and trembling aspen-balsam poplar(Populus balsamifera)/wild sarsaparilla (Aralia nudicaulis).

Reclamation of the mined land was conducted in 1979 prior to the monitoring study. The seed mix contained Canadian bluegrass(Poa compressa), creeping bentgrass(Agrostis palustris), creeping red fescue(Festuca rubra), crested wheatgrass (Agropyron cristatum), slender wheatgrass (A. trachycaulum), smooth brome(Bromus inermis), and timothy(Phleum pratense). Legume species included alfalfa and alsike clover (Trifolium hybridum). The re-established communities consisted largely of these species as well as invading grasses, forbs and shrubs (Kennedy 1986). The reclaimed mine area was planted in spring 1979 with lodgepole pine and white spruce seedlings at 1250 stems/ha.

Methods

Pellet Group Counts

Pellet group counts were used to determine moose and deer use of the study area. Moose and deer habitat utilization is expressed for both the test mine and surrounding habitat types by a "days-of-use" statistic, calculated according to the following formula:

$$\text{Days-of-Use} = \frac{\sum p^{i} \times 100}{\sum t^{i} \times 13} \quad (1)$$

where $\sum p^{i}$ equals the number of pellet groups in the i^{th} vegetation type, and $\sum t^{i}$ equals the number of plots in the i^{th} vegetation type. The plot size of 100 m² was standard in non-test-mine habitats; a smaller plot size (10 m²) was used on the test mine site. A defecation rate of 13 pellet groups per day was assumed for both moose and deer following Usher(1978), Connolly(1981) and Creed et al.(1984).

On the test mine, 50 permanently marked 2 x 5 m square plots were established. To allow complete coverage, the plots were distributed in a systematic manner. In June of 1978, 1980, 1983 and 1984, all pellet groups from the previous winter were counted and then removed from the plots.

Forest habitats adjacent to the test mine were categorized as shrubland, deciduous dominant, coniferous dominant and mixedwood forest. Within each habitat type, 20 plots were randomly placed along each of 10 transects (total 200 plots). In June of 1979, 1980, 1983 and 1984, all pellet groups from the previous winter were counted and then removed from the plots.

Use of Planted Deciduous Shrubs

To determine whether

moose and deer would forage on planted browse, three shrub islands of willow were constructed in spring 1979 on the test mine site. Stem cuttings were taken from local populations of willow growing in the vicinity of the test mine. Cuttings were from 0.75 to 1.5 cm in diameter and approximately 30 cm long. All side branches were clipped back to the main stem and planted within one day of being collected. Willow plants(N = 175) were distributed equally among the 3 "islands" at approximately 1 m spacings.

During May-June of 1981 to 1985, the degree of browsing of planted willows was evaluated. The percentage of current annual twigs browsed was classified as follows: no use (0), very light (1-9), light (10-39), moderate (40-59), heavy (60-89) and very heavy(90-100).

Diets of Moose and Deer

Fecal samples for moose and deer were collected during June, 1982, at each pellet group plot on the test mine. Composite samples were used for plant species identification (Holechek *et al.* 1982; Holechek and Gross 1982). Material from each composite sample was mounted on 10 microscope slides; 200 locations on each slide were examined to identify the presence of plant species in the diet.

Results

Habitat Use

Mean levels of days-of-use/ha by moose of the test mine site were higher than in adjacent forest and shrubland habitat over the study period, (Table 1)but not significantly so(Mann-Whitney Test, T=20, p>0.05). No evidence was found

TABLE 1. Moose(M) and deer(D) habitat utilization (days-of-use/ha) on Judy Creek test mine site and in adjacent habitats, as determined from pellet group counts 1978-85.

Habitat Type		YEAR OF SURVEY							
		1978	1980	1981	1982	1983	1984	1985	Mean
Test Pit Site	M		0.0	3.1	7.4	4.3	1.8	5.7	3.7
	D		5.4	14.8	5.1	21.3	6.3	1.4	9.0
Adjacent Habitats									
Shrubland	M	5.9	2.2			5.7	7.5		5.3
	D	1.4	0.3			5.7	1.4		2.2
Deciduous Forest	M	3.9	-			3.8	5.0		4.2
	D	1.5	-			4.8	8.7		5.0
Mixedwood Forest	M	5.1	3.5			4.3	2.4		3.8
	D	3.0	4.0			2.4	3.4		3.2
Coniferous Forest	M	1.2	0.4			2.5	0.8		1.2
	D	1.5	2.7			4.1	1.2		2.4

of moose using the test mine site in 1980, the year after test excavation. However, moose used the site in each of the subsequent years, with intensity varying from 1.8 (1984) to 7.4(1982) days-of-use/ha, and a mean of 3.7 days -of-use/ha(Table 1). No trend in use is apparent from the data. In relation to adjacent habitats, mean use by moose of the test mine site was greater than use of coniferous forest, equivalent to use of mixedwood forest, and less than use of deciduous forest and shrubland. Again, no year-to-year trend in days-of-use by moose was apparent from the data from adjacent habitats.

Use of the test mine site by deer was highly variable, with a 15-fold difference in calculated use levels among years(Table 1). Levels of use measured in adjacent habitats were also variable, but much less so than the test mine site. No evidence of deer using the test mine site was found in 1980, the year after excavation. Days-of-use/ha varied from 1.4(1985) to 21.3 (1983), with a mean of 9.0 (Table 1). In years when data are available for comparison, deer used the test mine site more frequently than all other habitat types in all years except 1984, when deciduous forest data show greater use. Mean days-of-use/ha was greater for deciduous forest than other adjacent habitats (Table 1).

Mean levels of use by deer of the test mine site have been higher than in adjacent forest and shrubland habitats over the total study period(Mann-Whitney Test, $\underline{T}=20$, $0.05<\underline{p}<0.10$). Overall, deer days-of-use/ha of both the test mine site and adjacent habitats fluctuated, with no trend apparent.

Deer used the test mine site twice as much as moose (total 54.3 vs. 22.3 days-of-use/ha during 1980-85), but the difference in use, when considered on a year-by-year basis, was not significant (Wilcoxon's Signed Rank Test, $\underline{T}=3$, $\underline{p}>0.05$).

Use of Planted Shrubs

Browsing of willows planted in 1979 was observed in 1980 and continued consistently from 1981 to 1985(Table 2). Of the 1,204 shrubs evaluated for browse use for all years, 318(26%) showed no use. For the most part, the remainder were browsed heavily(26%), moderately (20%) or lightly (16%). In the final year of evaluation (1985), more than half of the plants were browsed heavily. In other years, the proportions in each browse evaluation class remained relatively constant.

Diets of Moose and Deer

Five plant groups or genera were identifiable in fecal fragments of moose. Over 88% of the moose fecal fragments analysed consisted of willow(Table 3). One other genus(*Picea*) accounted for 8.1 % of the fragments, while the remaining identifiable groups or genera were minimally represented. Fecal fragments from deer were dominated by *Cornus* (31.2%), unidentified legumes (23.2%), and *Equisetum*(15.2%). Ten other groups or genera were also identifiable,

TABLE 2. Browsing of willow plantings on the test mine site. Numbers in parenthesis are percentages of total shrubs evaluated.

YEAR	Browse Use[1]						
	None	Slight	Light	Moderate	Heavy	Severe	Total
1981	42	15	25	25	35	11	154
1982	95	23	53	30	30	2	232
1983	43	16	48	75	77	8	267
1984	113	30	48	60	45	3	299
1985	25	4	15	52	131	25	252
Totals	318(26)	88(7)	189(16)	242(20)	319(26)	49(4)	1,204

[1] Browse use expressed as the number of plants browsed in each class. Classes are based on percentage of current annual twigs browsed, as follows: None(0), Slight (1-9), Light (10-39), Moderate (40-59), Heavy (60-89), Very Heavy (90-100).

principal among which were Populus, Rubus, Picea and Poa.

TABLE 3. Moose and deer food habits as determined by fecal fragment analysis.

Plant Group (Genera)	% Composition Moose	Deer
Graminoids		
Festuca	0.2	1.6
Poa	0.0	3.8
Forbs		
Legume (type)	3.0	23.2
Equisetum	0.0	15.2
Cornus	0.0	31.2
Woody Browse		
Picea(spruce)	8.1	4.0
Pinus	0.0	2.0
Populus	0.0	6.5
Rubus	0.0	4.2
Salix(willows)	88.1	1.6
Viburnum	0.7	1.6
Vaccinium	0.0	0.4
Lichen		
Letraria(type)	0.0	1.6

Discussion

Both deer and moose used the reclaimed test mine site to a level equivalent to use of adjacent habitats. Other studies have documented white-tailed deer(Beregovoy and Brucker 1983), mule deer (Medcraft and Clark 1986), and elk(Kuhn and Martens 1980) use of reclaimed mine sites. We are unaware of any studies documenting use of reclaimed mine sites by moose.

Our study did not attempt to determine seasonal differences in use or diets of deer and moose. In a study of mule deer and pronghorns(Antilocapra americana), Medcraft and Clark(1986) found that, year-round, mule deer used unmined land less than mined land reclaimed and seeded with alfalfa; however, pronghorns used unmined land more than the mined land owing to a greater dependence, particularly in winter, on native forages. In the Judy Creek region, there may be seasonal differences in the willingness of moose and deer to use the test mine site.

The results of our analysis of moose and deer diets indicate that moose in the study area are heavily dependent on willows for forage, while deer diet is more varied. Analyzed feces were collected from the test mine site only; however, we assume that the diets indicated represent foraging both on and off the mine site.

Our records of browsing on willows coupled with the dietary dependence of moose on willows suggests that the plantings are encouraging use of the test mine site by moose. Only a small proportion of deer feces fragments consisted of willow. The second most prominent genus in the diet of moose was *Picea*, suggesting that planted spruce were also being used. Fragments of the other planted tree species, *Pinus contorta*, were not found in moose feces.

The relationship of deer diets to the plant species used in revegetation is less clear. Both *Festuca* and *Poa* were found in deer feces fragments, and both were seeded on the test mine site. Legumes, perhaps including alfalfa, were prominent in deer feces fragments; however, the technique for analyzing fragments was incapable of determining legume genera or species. Alfalfa is known to attract deer to use other reclaimed mine sites, and to dominate their diet in spring and fall(Medcraft and Clark 1986). Willows, *Picea*, and *Pinus* fragments were present in deer feces. At Judy Creek, assuming that all legume fragments are from seeded forbs, and that graminoids and woody browse genera fragments are from seeded or planted sources, the majority of deer fecal fragments were from species or genera that were not used in revegetation. This suggests that deer spend more time feeding in (cf. moving across) areas other than the test mine site.

Conclusions

Our monitoring study documented that deer and moose used a reclaimed mine site in west-central Alberta within 1 year of revegetation. To our knowledge, the response by moose has not been previously recorded in published literature. No trends in the amount of use by deer or moose are apparent from our data. Planted willows were consistently browsed from year to year, and fecal fragment analysis suggests that moose will be attracted to revegetation with willows. Graminoid genera used in revegetation also occurred in deer fecal fragments, but much less often than forbs and woody browse. Our data and other studies suggest that revegetation using seed mixes with a greater proportion of legumes will attract deer.

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CHANGES IN FISH POPULATIONS AND HABITAT AT A RECLAIMED MULTIPLE RIGHT-OF-WAY STREAM CROSSING[1]

by
J. H. Allan and A. Lees[2]

Abstract. Between 1964 and 1973, two large diameter pipelines and a power transmission line were constructed across the Raven River in western Alberta. The stream channel within the right-of-way after construction was wider, shallower and had little cover for fish, and the streambanks lacked a stable riparian vegetation community. Little natural recovery of the fish habitat within the disturbed channel has occurred since the last disturbance in 1973. In 1984, a project to reclaim the channel and evaluate the effect of the reclamation on habitat and fish populations was initiated. Bank overhang, logs, stumps and woody debris and aquatic vegetation were measured during the spring and summer from August 1984 to August 1988. Reclamation measures used were vertical log wall, artificial plank overhang, stumps, log deflectors and tree revetments. Reclamation measures increased the amount of available log and stump cover by an average of 146%, and bank overhang cover increased by an average of 245%. Fish populations were investigated by electrofishing to obtain data on abundance, age, growth and habitat utilization in the reclaimed section and in a control section. Trout numbers exhibited a general increase over the study period. The young-of-the-year cohort of the brook trout population and the one-year-old-and-older cohort of the brown trout population showed moderate increases in abundance in response to the reclamation. Increases in the abundance of the one-year-old-and-older cohort of the brook trout population attributed to the reclamation measures exceeded 350%.

Additional Key Words: streambank reclamation, fish populations, right-of-way reclamation.

Introduction

Between 1964 and 1974, two large diameter underground pipelines and an overhead power transmission line were constructed across the Raven River in western Alberta (52°02'50"N, 114°53'30"W). Twenty years after the first disturbance at this site, visual comparison with adjacent undisturbed reaches of the river revealed that in-stream fish habitat within the right-of-way had recovered only marginally. The stream channel through the right-of-way was shallower and more exposed, with less cover, and had a less diverse riparian vegetation community than the undisturbed channel.

In 1984, a program of reclamation and research was initiated at this site to evaluate changes in fish populations and habitat as a result of reclamation.

Study Area

The Raven River is a foothills trout stream with stable flow regimes such that stable, high-quality habitat for cold water fish species has evolved. Both eastern brook trout (Salvelinus fontinalis) and brown trout (Salmo trutta) were introduced and have subsequently established self-reproducing populations. The study used two sections; Section A encompassed the multiple right-of-way, and Section B was an undisturbed portion of the Raven River immediately downstream of Section A.

Methods

Fish populations were sampled with backpack fish shockers. Population estimates were determined using the Chapman modification of the Peterson mark/recapture formula (Ricker 1975). Criteria for validity of the estimates were taken from Robson and Regier (1968). Ranges were calculated using the 95% confidence interval and a "t" test (P = 0.05) was used to determine the significance of differences between parameters. Correlation analyses were used to examine the relationships of a number of parameters (Robson and Regier 1968).

Electrofishing was conducted in Section A in August 1984 and in both sections in both April and August from 1985 to 1988.

Habitat conditions prior to and after reclamation in Section A were measured using two methods, both involved the use of line transects established at right angles to the flow. At each transect the extent of aquatic vegetation, logs, stumps and woody debris and overhanging bank was measured. These measurements were then used to calculate the area (m^2) of each habitat component. In addition, six permanent transects were established where data on channel width, water depths, substrate and cover was collected and compared to transects established in Section B.

Reclamation was done in May 1985 and July 1988. A total of 120 metres of anchored vertical log wall were placed along those sections of bank deemed most unstable and offering the least cover. Portions of two of the log wall sections included an artificial underwater plank overhang, and portions of two sections incorporated an above-water deck overhang. Nineteen stumps with root wads were anchored at various locations along the log walls. A tree revetment was placed upstream of one log wall and two log deflectors were placed in the stream channel. The areas backfilled behind the log walls were revegetated by seeding a grass/legume mixture, transplanting native shrubs and fertilizing. The configuration of the reclamation measures is summarized in Figure 1.

Results

Habitat

The reclamation completed in 1985 increased the amount of log and stump cover by 17.3 m^2 (132%), and bank overhang cover by 16.5 m^2 (175%) over

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[1] Paper presented at the Conference 'Reclamation, A Global Perspective,' Calgary, Alberta, August 27-31, 1989.

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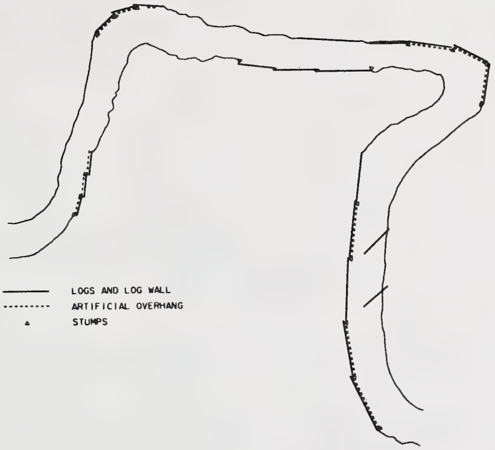

Figure 1. Configuration of Reclamation Measures

1984. The reclamation completed in 1988 increased log and stump cover by an additional 5.67 m^2 (24%) and bank overhang cover by 17.42 m^2 (79%). A major flood in the summer of 1986 substantially reduced the amount of naturally occurring logs, stumps, and bank overhang in the study section. In Section A there was greater than 50% reduction in log and stump cover and nearly a 50% reduction in natural bank overhang as a result of the flood. However, the flood had little effect on the artificial structures.

Fish Populations

Fish populations varied over the study period. The number of young-of-the-year brown trout in the reclaimed section varied from a low of 43.8/100 m in 1985 to a maximum of 2523.8/100 m in 1987. The number of young-of-the-year brown trout was correlated with the discharge in the previous spawning season ($P<0.05$), and was not related to habitat availability. The number of one-year-old-and-older brown trout ranged from a minimum of 40.2/100 m in 1986 to a maximum of 322.8/100 m in 1988. The abundance of the one-year-old-and-older cohort in the reclaimed section was dependent on both area of available cover and year class strength. This relationship was so strong that the effects of year class strength and habitat could not be separated (Multiple Correlation Analysis).

Young-of-the-year brook trout numbers in the reclaimed section ranged from 39.8/100 m in 1984 (before reclamation) to a high of 302.5/100 m in 1988. Young-of-the-year brook trout numbers were consistently higher in the reclaimed section than in the control section. These differences were statistically significant ($P = 0.05$) in three of four years. Although the relationships between a number of environmental and biological variables and young-of-the-year brook trout numbers were consistently poor. The abundance of the one-year-old-and-older cohort of the brook trout population in the reclaimed section ranged from 23.9/100 m in 1987 to a maximum of 42.2/100 m in 1988. The area of available cover was strongly correlated to the abundance of this cohort ($r = 0.83084$, significant at $P = 0.05$). The one-year-old-and-older segment of the brook trout population was consistently more abundant in the reclaimed section than in the control section.

Discussion

Young-of-the-year brown trout increased in abundance in the reclaimed section of the stream channel, but not in response to the reclamation measures. The one-year-old-and-older cohort of the brown trout population responded positively to the increased cover resulting from reclamation. However, their numbers were also positively related to year class strength. Lowry (1971) suggested that increasing abundance of young brown trout might be affected more by other environmental variables than by habitat enhancement, whereas the positive response of older brown trout in enhanced streams is largely directly due to habitat improvements.

Saunders and Smith (1962), Hunt (1971, 1976) and Latta (1972) noted that one-year-old-and-older brook trout exhibited a greater positive response to habitat improvements than did the age 0 (young-of-the-year) cohort. In the Raven River, both the age 0 and the one-year-old-and-older cohorts of the brook trout population responded positively to the reclamation measures. The one-year-old-and-older segment of the brook trout population exhibited the strongest response of any cohort, although the magnitude of the changes was less than that demonstrated by the brown trout population.

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SEASONAL AND SPATIAL DISTRIBUTION OF BIGHORN SHEEP AT AN OPEN PIT COAL MINE IN THE ALBERTA FOOTHILLS[1]

by

Beth MacCallum[2]

Abstract. Mining activity at Cardinal River Coals Ltd., an open pit mining site in the Alberta foothills, drastically changed the landscape from a closed canopy coniferous forest to open terrain consisting of reclaimed meadows in proximity to unreclaimed pit walls. A population of approximately 200 bighorn sheep which had been using the mine lease was studied during the year 1985-86. Ranges for the prerut, rut, winter and spring seasons were variously located on the lease area, as well as features such as lambing walls and mineral lick sites. High walls of exhausted pits were used for escape terrain and travel routes. Recommendations were made to the Alberta Land Conservation and Reclamation Council regarding maintenance of high walls in association with reclaimed meadows as integral components of bighorn sheep habitat. This site-specific wildlife study should be invaluable for mine planning and reclamation efforts.

In 1985, Cardinal River Coals Ltd. (CRC) initiated a population study of a herd of bighorn sheep that had been using their mine lease site for several years. CRC is an open pit coal mining operation that is situated in the foothills of west central Alberta 50 km south of the town of Hinton. CRC began mining activities in 1969 and reclamation work in 1971. Disturbed areas of the mine lease are being reclaimed for wildlife habitat and recreation as required by The Coal Development Policy for Alberta (Department of Energy and Natural Resources, 1976). Wildlife habitat was chosen as the end use because viable wildlife populations were present in the vicinity of the mining lease and reclamation costs were less than returning the disturbed land to timber production. Wallis and Wershler

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[1] Paper presented at the 1989 conference of the Canadian Land Reclamation Association and the American Society for Surface Mining and Reclamation, Calgary, Alberta, August 27-31, 1989.

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(1979) developed guidelines for reclaiming the CRC lease to bighorn sheep, mule deer, elk and moose habitat. Since that time, however, bighorn sheep have become the common species using the mine lease.

The purpose of this study was to obtain baseline data on the population of bighorn sheep at CRC in order to establish a long term monitoring program. The work was undertaken by the author as part of a Master's Degree Program at the Faculty of Environmental Design, University of Calgary during the year 1985-86. This paper discusses a portion of that work, concentrating on seasonal and spatial distribution of the bighorn sheep on the mining site and the implications this use has for reclamation efforts. Descriptive techniques will largely be used in the discussion of this work, because research is not quite finished.

I wish to thank W. D. Wishart for providing critical review throughout the duration of this study. G. B. Acott helped to initiate the work and has provided continual support. Dr. V. Geist and Dr. M. Bayer also contributed to the study. Financial support for this project was supplied by CRC and the Recreation, Parks and Wildlife Foundation of Alberta.

Study Area and Population

The study area is defined by CRC's Mineral Surface Lease # 5972 located in TWP 47 and 48, Rge 24, W of the 5th Meridian. As of December 31, 1986 a total of 43.9% or 1250 ha (3,088.6 acres) of the lease area had been disturbed, of which 504.3 ha (1246.1 acres) were in some stage of reclamation (Acott et al. 1987). The mineral surface lease is bounded on the west side by Gregg River, the north by Mary Gregg Creek, the east by tributaries of Luscar Creek and on the south by the front ranges that encompass Whitehorse Creek. The mine is bisected by Hwy 40 (Figure 1).

The study area is typified by rolling topography and steep slopes of uplifted Mesozoic shales and sandstones. Elevation of the mine ranges from 1680 to 1860 m a.s.l. (5512 to 6102 feet). Prior to mining, the study area was almost entirely forested with a closed canopy Subalpine spruce/fir forest. Forested areas are dominated by hybrid spruce (*Picea glauca* x *engelmannii*), lodgepole pine (*Pinus contorta*), fir (*Abies lasiocarpa*) and black spruce (*Picea mariana*). Aspen (*Populus tremuloides*) occurs on exposed, warm, south-facing slopes. Most timber within the lease is non-merchantable which is defined as <15.2 m (50 ft) high, <20.3 cm (8 in) dbh, <4 per ha (10 per acre). Soils of the study area are generally orthic gray luvisols on fine textured parent materials or eluviated brunisols on coarser textured materials.

The mining sequence involves site preparation by first salvaging or removing the timber resource. The topsoil and upper regolith layers are then salvaged and stockpiled. Finally, overburden is removed from the pit and used to backfill an existing pit or dumped externally onto an area where no previous mining activity has occurred.

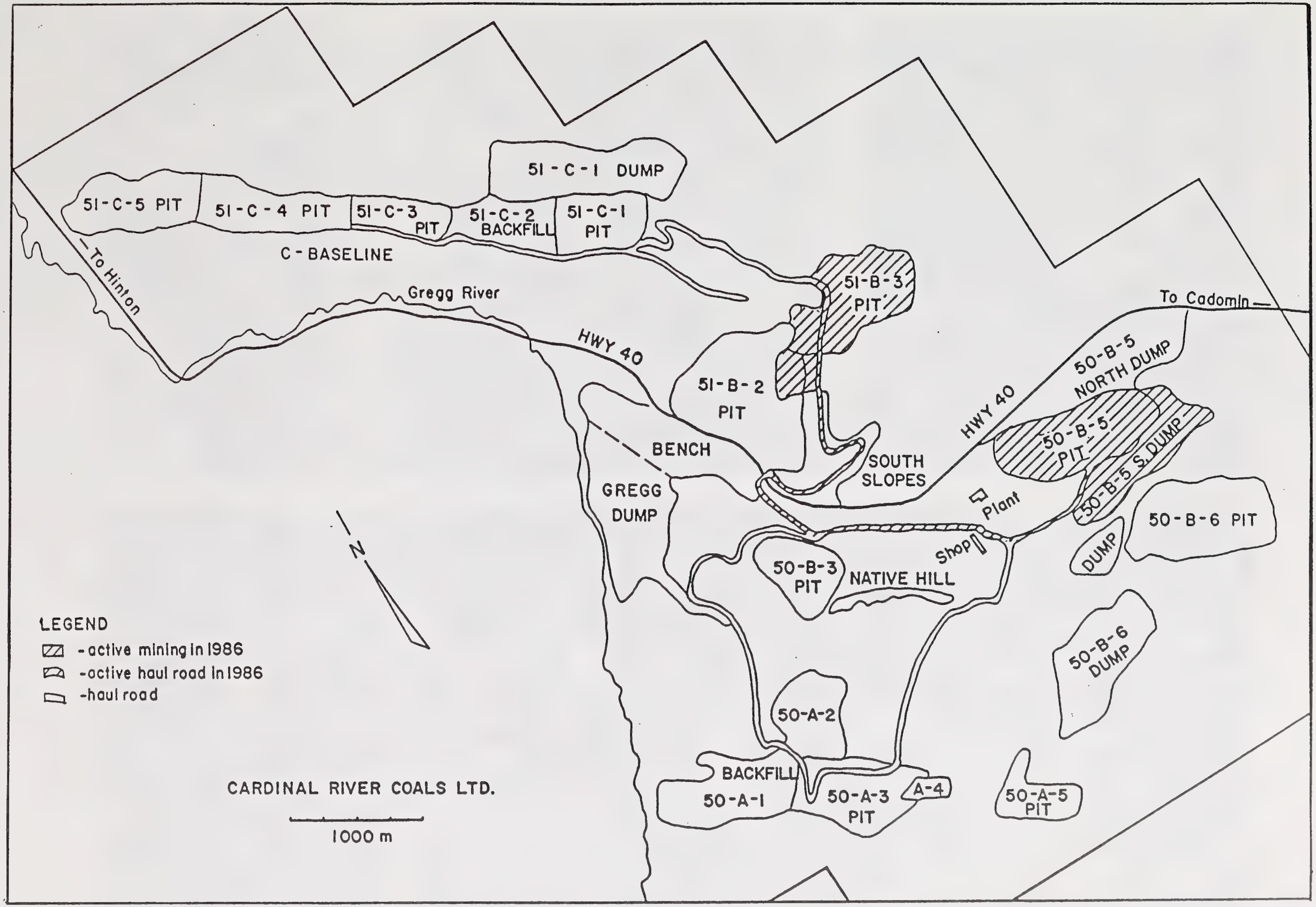

Figure 1. Location of pits, dumps and backfills at Cardinal River Coals Ltd., 1986

Following the mining activities, the dumped or backfilled overburden is graded and recontoured to a slope angle of 27o or less. Regolith is placed over the entire surface to a depth of 15 cm (5.9 in), and topsoil islands are placed in favourable locations. The whole area is then seeded and fertilized and the topsoil islands reforested.

Agronomic species are used for seeding in roughly a 50-50 grass/legume mixture. Grasses used are a combination of sod-forming and bunchgrasses - streambank wheatgrass (*Agropyron riparium*), smooth brome (*Bromus inermis*), red fescue (*Festuca rubra*), Canada bluegrass (*Poa compressa*), Kentucky bluegrass (*Poa pratensis*), crested wheatgrass (*Agropyron pectiniforme*), orchard grass (*Dactylis glomerata*), Russian wild ryegrass (*Elymus junceus*), tall fescue (*Festuca arundinacea*), hard fescue (*Festuca ovina*) and timothy (*Phleum pratense*). Legumes used are cicer milkvetch (*Astragalus cicer*), rambler alfalfa (*Medicago media*), sweet clover (*Melilotus spp.*), sainfoin (*Onobrychis viciifolia*) and alsike clover (*Trifolium hybridum*).

Approximately 250 bighorn sheep currently use the lease site from late summer to late spring. The sheep use reclaimed areas for foraging and the high walls of exhausted pits for escape terrain and travel routes. Sheep travel over non-reclaimed overburden and through active mining sites to gain access to forage areas. Some reclaimed areas located at distance from high walls are not used for forage, while some pits surrounded by coniferous forest or non-reclaimed overburden are not used for travel or escape.

A limited non-trophy sheep hunt was held in the fall of 1984, 1985 and 1987 on a reclaimed portion of the lease area. In addition, the Alberta Fish and Wildlife Division uses this site for capturing sheep for various purposes. A total of 84 sheep have been removed by hunting or other methods over the 4 year period ranging from 1984 - 1987. Eighty-two percent of these animals have been mature females.

Prior to the current mine development, rams were known to use old mine workings in the vicinity of the 50-A-3 pit for mineral licks. Surveys conducted by the Alberta Fish and Wildlife Division (Lynch 1972, Cook et al. 1978, Cook 1982) indicate that sheep were sighted on alpine ranges adjacent to the mine lease as well as on the 50-A-2 backfill. By 1979, large numbers of sheep of all age classes were frequenting reclaimed areas on the mine lease adjacent to timberline and were using the reclaimed south-facing slopes above HWY 40 (G. Acott, CRC, pers. commun.).

Methods

Animal observations in the field were made by direct ground counts from a fixed census route. Counts were begun September 17, 1985 and continued weekly until September 1, 1986. During each count, the location of each individual or group of sheep was marked on acetate overlays on a 1:4,800 base map. Notes were also made on the age class and activity of each individual within the group. Eight age classes described by Geist (1971:54) were used. They were: lambs, yearling females, adult females, yearling rams, class I (2 yr) rams, class II (3-5 yr) rams, class III (6-7 yr) rams and class IV (8+ yr) rams. A total of 11,933 individual sightings from 138 census trips provided the data base for describing seasonal and spatial distribution of the sheep. Maximum counts of each age class were used to estimate population size for use in depicting seasonal fluctuations of the sheep herd on the lease.

Field data were computerized by coding and digitizing observation locations and by generating a corresponding database containing the numbers, age classes and activities of sheep associated with each location. Maps of data subsets and their locations that depict the cumulative frequency of observations per time period were then generated using the "nmap" program developed by the graphics laboratory at the Faculty of Environmental Design. A grid system with a cell size of 402 x 402 m (1320 x 1320 ft) or 16.2 ha (40 acres) was overlaid on the study area to assist in quantitative and visual analysis of the data. Cell size was arbitrarily selected. Data from the eight age classes were grouped into 2 categories - nursery herd (lambs, ewes, female and male yearlings and class I rams) and older rams (class II, III and IV rams).

Results

Seasonal Distribution

The rams that used the CRC lease during the year of 1985-86 made four seasonal movements which were described as: the fall congregation (prerut), the rut, winter segregation from the nursery herd and dispersal into adjacent alpine ranges during the summer.

The prerut, or fall congregation of rams onto the mine site had already taken place when the study began on September 17, 1985. Rams remained segregated from the nursery herd until early in November when they moved onto the rutting area, which was also the ewe prerut range. The rut was defined as the period when rams and estrous ewes were observed (November 15 to January 18, 1986). The peak of the rut occurred during the second week of December, 1985. In mid-January, the rams segregated from the ewes leaving them on the rutting range. The rams occupied a native south-facing slope that is centrally located on the lease. The rams alternately used this slope and the south-facing slopes above HWY 40 throughout the winter and spring until they began to leave the lease in late May. During the summer, groups of rams were sighted travelling between various alpine ranges. Only the occasional individual or small group was observed on the mine lease.

Four major movements were also observed for the nursery herd that occupied the CRC lease: fall congregation on the mine site (prerut), movement off the mine site by half the herd in late winter, movement to lambing grounds in May and dispersal into alpine ranges for the summer months.

The nursery herd had already congregated on the lease when the study began in September, 1985 where they remained for the rut and early winter season. In mid-February, half the herd left the mine site to winter elsewhere, while the remaining sheep continued to use essentially the same ranges as they had for the prerut, rut and early winter. In mid-May individual ewes began to leave the mine site in search of lambing areas. Most lambing occurred off the mine site with the exception of 6 ewes in 1986 and 5 in 1987 which lambed on the east wall of the 51-B-2 pit. The nursery herd regrouped in alpine meadows adjacent the mine site and used the 50-A-3 pit as a mineral lick throughout the month of June. During the summer, the nursery herd did not frequent the mine lease, but continued to move higher into the headwaters of alpine drainages as the season progressed.

When the above movements for both ewes and rams were combined, 6 seasonal activity periods were identified. These time periods were as follows:

Prerut	- 09/17/85 to 11/14/85
Rut	- 11/15/85 to 01/18/86
Winter	- 01/19/86 to 02/14/86
Spring	- 02/15/86 to 05/27/86
Lambing	- 05/28/86 to 06/30/86
Summer	- 07/01/86 to 08/10/86

Of the 11,933 individual sheep observations made between September 17, 1985 and August 10, 1986, 73% were lambs, ewes or yearlings of either sex, 5% were of class I rams and 22% were of older rams. Sheep were concentrated on the lease from the prerut through to the beginning of lambing season, a period of 256+ days for the 1985/86 season. The prerut period for the 1986/87 season began August 11 when the first large numbers of ewes, lambs, yearlings and class I rams began to appear on the lease. Older rams (class II, III and IV) did not congregate in large numbers for the 1986/87 prerut season until a few weeks later, in early September.

Spatial Distribution

Approximately 1/3 of the observations for the nursery herd (9,349) for the year 1985/86 were made within 32.4 ha (80 acres) of the 50-A-1 and 50-A-2 backfill (Figure 1). Another 1/3 of observations were made within an additional 32.4 ha of the 50-A-2 backfill and within 48.6 ha (120 acres) of the south slopes and valley bottom adjacent to HWY 40. The last 1/3 were scattered over 696 ha (1720 acres) of the lease. The total area used by the nursery herd for grazing, security, mineral licks or travelling within the lease boundaries was 809.4 ha (2000 acres).

Of the 2,584 observations made of the older rams, 1/3 occurred within 32.4 ha of the 50-A-1 and 50-A-2 backfill, plus a 16.2 ha block of the native hill and a 16.2 ha block of the south slopes above HWY 40. An additional 1/3 of observations were scattered over 113.3 ha (280 acres) located on the 50-A-2 backfill, on the slopes adjacent to HWY 40, and on a topsoil stockpile located on the C-baseline ridge. The last 1/3 of observations were located on 696 ha of the lease. The total area used by the older rams was 874 ha (2160 acres).

From the above description it is apparent that the most important area used by the sheep on the mine site is the 50-A-1 and 50-A-2 backfill. This area was reclaimed in 1977, 1978 and 1979 and is used for grazing by the nursery herd during the prerut, rut, winter and spring seasons. Rams congregated here for the rut, during which time the high walls of the adjacent 50-A-3 pit were used heavily by ewes escaping rams and by rams attending receptive females. The benched walls of this pit were used as escape sites, bedding areas, and in May and June the seeps from the walls were used as mineral licks by the nursery group that used the Luscar Creek valley immediately west of the lease. This daily movement was a response to the need for minerals as virtually no grazing took place on the mine at this season.

The sheep also made moderate to heavy use of the native grassed slopes of the large hill that is centrally located on the mine lease. This south-facing slope was used primarily by rams during the winter and spring period when they had segregated from the nursery herd. Heaviest use of this hill was on the NW corner which lies adjacent to the 50-B-3 benched pit wall. This slope and pit wall were used by the nursery herd chiefly as a travel route connecting the 50-A-2 backfill with the HWY 40 area.

The nursery herd used the south-facing slopes and valley bottoms adjacent to HWY 40 heavily during the prerut and spring seasons, while the rams used this area heavily in the winter and spring. This area was seeded in 1976. The east wall of the nearby 51-B-2 pit was used as escape terrain by the sheep when they frequented this area. In May of 1985 and 1986, 6 and 5 ewes respectively lambed on this wall. In 1986, these lambing sites were within a few hundred metres of an active dump site. Most lambing, however, took place off the lease.

Moderate use of the large bench and slopes of a portion of the Gregg dump was made by the nursery herd during the prerut This part of the Gregg dump was reclaimed in 1972 and 1979/80.

Rams also used a topsoil dump located on the C-baseline. This area received heavy use during the prerut. A powerline located on the C-baseline was reclaimed in 1978 while the topsoil island was reclaimed in 1983. Rams have been observed on the C-baseline by mine personnel since 1970.

Discussion and Conclusion

Mining activity at CRC has resulted in a drastically changed landscape. The closed canopy coniferous forest of the central portion of the lease has been replaced by open terrain composed of reclaimed areas, active and abandoned pits and non-vegetated regolith material. Patches of the original coniferous forest and native grasslands are interspersed throughout the mined area. The common feature of bighorn distribution, (the presence of rocky escape terrain in proximity to quality forage) has been reproduced through the process of mining development and reclamation. Every area on the lease that was used heavily by the sheep for foraging was located adjacent to high walls of exhausted pits. These high walls served as escape terrain for the sheep, as bedding sites, as travel routes, and as sources for mineral licks. Some lambing occurred on benches of the high walls. Seventy-five percent of all sheep observations for the year 1985/86 occurred within 360 m (1181 feet) of escape terrain. No observations of sheep beyond 705 m (2315 feet) from escape terrain were made.

In addition to creating a usable habitat for bighorn sheep, other conditions that exist within the mine lease created a secure environment which was used by the sheep in an opportunistic fashion. Coyotes were observed often on the sheep ranges, however, no predation was observed. Grizzlies travelled through the mine seasonally, but did not linger on the reclaimed areas. Wolf tracks were observed on the peripheral edges of the lease but never in the central portion or on sheep ranges. Cougar sign was not observed. It is thought that while the sheep were on the lease, mortality from predators was minimal.

CRC has been an active coal mining operation since 1969. During the 1985/86 season, 2 pits were active (51-B-3 and 50-B-5). Dumping, grading, regolith and topsoil placement, reseeding and refertilizing activities all took place in areas utilized by the sheep. For the most part, however, these activities occurred in a predictable fashion, or in areas not yet used for forage, or in the summer when there was minimal use of the lease by the sheep. Once a reclaimed area was established on the lease, little activity actually took place on the site. There were no tourists, trail bikers, hikers or skiers. Hunters have been active only recently on the same ranges that are important to the sheep.

Bighorn sheep are modern ice-age mammals that have developed a high capacity for learning. Bighorns have historically used the areas adjacent to the CRC lease prior to its development. Once a usable habitat was developed by mining activity, the sheep were well equipped to take advantage of the predictable, secure environment offered by the mining site.

A significant population of bighorn sheep has developed seasonal and spatial use patterns on the CRC lease. Several factors must be considered and explored further to ensure that this use is sustained in the long term to be of benefit to other developments with similar potential. The significance of the high walls as part of bighorn habitat was not recognized by the Alberta Land Conservation and Reclamation Council (ALCRC) until this study was conducted. Recommendations regarding maintenance of high walls important to sheep have been made to the ALCRC (Acott, 1986) and have been accepted. Recommendations on high wall characteristics and placement in relation to foraging areas will be forthcoming. Future land management must recognize that sheep use of this site in part depends on a secure and predictable environment. Reclamation efforts designed specifically for human recreation activities may not be compatible with sheep use of the area if they are poorly placed in relation to habitat developed for sheep. Each sheep population and mine operation have their own characteristics. This site-specific wildlife study has proven to be invaluable for mine planning and reclamation efforts.

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Publication in this proceedings does not preclude authors from publishing their manuscripts, whole or in part, in other publication outlets.

THE CREATION OF A MOUNTAIN LAKE SPORTFISHERY AT CARDINAL RIVER COALS LTD.[1]

by

Gerald B. Acott[2]

Abstract. Cardinal River Coals, Ltd. produces 2 Million Clean Short Tons of metallurgical grade coking coal annually for the export market. The primary focus of reclamation at CRC, Ltd. is the development of wildlife habitat with particular emphasis on Rocky Mountain Bighorn Sheep. A secondary objective of recreational development has been applied in our 50-B-6 Area with the creation of a lake. Shoreline recontouring, littoral zone construction, macrophyte/plankton innoculation and habitat enhancement techniques have been utilized in an attempt to provide a viable sportfishery. Progress to date is being monitored by a continuing limnological study to determine rate of food chain development leading to recommendations for a sportfish stocking program.

Introduction

Cardinal River Coals Ltd. (CRC Ltd.) is an open pit coal mine located approximately 500 km (310 miles) northwest of Calgary. The operation has produced over 32 Million Clean Short Tons of metallurgical coking coal since its inception in 1969, most of which has been purchased by the Japanese for steel manufacture.

Initial reclamation activities began in 1971 focussing on the creation of wildlife habitat. Open grasslands adjacent to unreclaimed highwalls provide excellent habitat for the resident herd of Rocky Mountain Bighorn Sheep, which has grown to a maximum count of 281 individuals. Reforestation has been limited to areas where microsites are more conducive to wind protection and moisture retention; these areas will cater to deer/moose utilization.

Current reclaimed land use planning has expanded to include recreational use. The creation of a mountain lake sportfishery in the 50-B-6 Pit is one example of this diversification.

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[1] Paper presented at the Conference Reclamation; A Global Perspectual, Calgary, Alberta, Canada, August 27 - 31, 1989.

[2] Gerald B. Acott, P. Biol., is the Environmental Co-ordinator at Cardinal River Coals, Ltd., Hinton, AB TOE 1BO.

Table 1

Morphometric Data for 50-B-6 Lake

	Metric	Standard
Volume	6.5M m^3	5,244 ac ft
Maximum Length	817 m	2,680 ft
Maximum Width	277 m	910 ft
Maximum Depth	100 m	328 ft
Mean Depth	44.6 m	146 ft
Shoreline Length	1944 m	6,380 ft
Area-Total	16.0 Ha	39.5 ac
-Littoral Zone	0.7 Ha	1.7 ac

Hydrological Planning

The 50-B-6 Pit (Table 1) was a deviation from the normal open pit mining technique employed at CRC Ltd. In most situations, a series of pits are planned along the strike of a coal structure where it nears the surface. Overburden from the initial pit is dumped externally; future excavations then backfill the previous pit. Internal phasing often allows partial backfilling of the final pit in the sequence.

The 50-B-6 Pit, however, was a single pit where coal removal was justified as a result of a small creek valley which reduced topography immediately above a section of the coal structure. The reclamation costs involved with rehandling sufficient overburden for backfill after mining to achieve the 27° final slope angle specified in our government approval would have been prohibitive. As the pit was located in a natural creek valley and water supply could be guaranteed, a decision to reclaim the pit as a lake was made at the outset, and approved by the government agency.

The proximity of mining at CRC Ltd. to the front ranges of the Rocky Mountains result in a number of small drainages passing through the site. Each of these basins respond immediately to precipitation events and, because the watershed is largely above treeline, low catchment factors coincide with high flow regimes. Luscar Creek and Jarvis Creek West both flowed through areas of future pit development and a diversion plan was required.

Luscar Creek contained a small lake within the drainage. This had been used as a water supply for the old townsite of Luscar between 1921 and 1955. CRC Ltd. installed a dam structure in the early 1970's to expand the size of Luscar Lake such that it could be utilized for domestic water use, coal processing and fire protection. This dam provided an opportunity for the flows of Luscar Creek to be diverted into Jarvis Creek West which would feed the completed 50-B-6 Lake. This extra flow greatly improved the filling and flushing rate in addition to offering a source of warmer water with a developed benthic and plankton base to innoculate the new lake.

Post Mining Construction

The most critical factor for the successful construction of a productive lake in the 50-B-6 Pit was the development of adequate littoral zone. These shallow areas would allow good light penetration for macrophytic growth and warmer water temperatures contributing to the establishment of a diverse and abundant lower food chain population. It was also important to make the shoreline of the lake accessible to recreational users.

In an open pit with overall wall angles of 50-55°, opportunity for shallow areas (3 metres of water or less) and approachable shorelines is somewhat limited. It was accomplished in the 50-B-6 area using various techniques. Resloping of backfilled overburden was required at the west end of the lake to achieve a 27° slope angle. Additional material was carried to final water level to create a small terrace. The extra cost to move the material was unjustified, however, as much of the terrace was lost to settlement after innundation. A safety bench on the north highwall, 8 metres (26 ft) in width, also provided some useable shallow area which continues to function as a littoral zone.

The south and east sides of the pit wall contained a wide bench which had been constructed to carry the flows of Jarvis Creek West in a 48" culvert during the period of active mining. A pit bottom access ramp immediately below the bench provided an excellent catchment area for overburden material so a blast casting technique was utilized to reduce the slope to the final shoreline in this area. A BE45R production drill was utilized to drill 27 cm (10-5/8 in) holes on a 4.6 m by 9.2 m (15 ft x 30 ft) spacing and was loaded with Anfo blasting agent to a powder factor of about 1.3. Holes were drilled to a subgrade of 3 m (10 ft) below the 27° final contour.

A total of 124,887 BCM (163,337 BCY) were blasted at a cost of $.29 BCM ($.38 BCY) for a total cost of $62,068. Komatsu 355 dozers were then utilized to grade the material to the final 2:1 slope angle such that topsoil material could be applied. This drill/blast/reslope technique is the most cost effective method of achieving the required 27° final slope angle and will be used in the reclamation of many future pit highwalls.

The majority of the littoral area of the 50-B-6 Lake was constructed at the east end where the lake water exits to the natural channel of Jarvis Creek West. D9L dozers were used to excavate a 0.57 Ha (1.4 ac) area in the downstream gravels and move the material into the pit. Final water depth within the basin averages 1 m (3.3 ft). A berm was constructed to final water elevation to separate the warmer more productive shallow area from the main body of the lake which also serves to intercept the heavy wave action during windy periods.

In each of these mini projects for littoral zone creation, intensive surveying was required to ensure good elevation control. Continuous laser monitoring proved to be an excellent method as it allowed the equipment operators to control elevation as construction proceeded.

A total area of 0.70 Ha (1.73 ac) of littoral zone was developed. Although this constitutes only about 5% of the total lake surface area, further development would have involved placement of backfill at a prohibitive cost. The remedial work done provided shallow area over 36% of the lake perimeter and accessible approach to 44% of the shoreline.

Soil material was spread on recontoured areas above water level as well as on some littoral zone and revegetated with a diverse grass/legume mixture. In addition, highwalls on the north side were seeded by helicopter and have shown an impressive catch. Bighorn sheep and mule deer regularily utilize the lake area.

Habitat Enhancement

Development of the lake included some enhancements to improve the fishery potential. A number of large truck tires were placed on the shallow safety bench area. These tires measure approximately 3 m (10 ft) in diameter and offer a substantial surface area for periphyton attachment. They also have a large internal area which fish may utilize similar to an overhanging bank in a stream environment. These artificial reefs will increase feeding potential within that area of the lake and should a deep water species such as Lake Trout (Salvelinus namaycush) be introduced at a later date, may also be utilized for spawning.

The littoral zone at the outflow and along the southeastern edge of the lake was topdressed with organic soil such that these areas could support a strong macrophytic plant community. Partially decomposed hay was "walked into" the soil with a small dozer to further increase the organic content and offer suitable benthic invertebrate habitat. An experimental macrophyte innoculation program was then initiated from a natural lake near the site. Special barrels were fabricated which were filled with underwater plant material and detritus from the natural lake and transported by helicopter to the 50-B-6 area to be spread in the shallows. Pondweed (Potamogeton richardsonii and P. vaginatas) and Northern Watermilfoil (Myriophyllum exalbescens) were the predominant species and preliminary results indicate good survival and growth rates. A further transplant program is planned for spring of 1989.

Prior to mining, fisheries monitoring in Jarvis Creek West showed strong seasonal use of Rainbow trout (Salmo gairdneri) relative to other small tributaries in the immediate area. Resident adults, juveniles and young of the year were represented and spawning was observed. In an attempt to improve the spawning potential immediately downstream of the lake, a habitat improvement program was undertaken in the late summer of 1987. A gabion mat with geotexile underlay was installed at the outflow of the lake to ensure a constant water level. A plunge pool was excavated to a 4 m (13 ft) depth immediately below the mat which then fed the original stream channel. Small step dams were constructed on 8 m (26 ft) intervals along the stream by installing logs extending across the bed and keyed into the bank on each side. Fine washed gravel was placed behind each dam to a depth of 15-20 cm (6-8 in). The action of the water creates a small pool immediately below each dam with fresh aerated water upwelling through the washed gravel at the tail of the pool which is held in place by the next dam. This technique was used in a repeating fashion for a total of 75 m (250 ft) downstream interrupted by an additional two large pools excavated to a minimum depth of 4 m (13 ft). Rainbow and Brook trout (Salvelinus fontinalis) were observed during the summer of 1988 moving upstream through the step dams and into the lake. Spawning is expected to occur as early as spring of 1989.

Limnological Investigations

Two limnological studies have been conducted to date on 50-B-6 Lake. The first (R.L. & L. 1987) was undertaken in 1986 while the lake was filling and included surveys at the end of July and in early October. Shoreline erosion and constant turbulence as a result of methane released from the coal caused the water to be very turbid yielding Secchi disc measurements of less than 0.3 m (1 ft). The lake had stratified by mid-summer with a distinct thermocline at 6-7 m (20 ft) below which oxygen was severely depleted. High levels of nitrogen and phosphorous were observed and concern was expressed about a possible algal bloom and related biological oxygen demand. Benthic invertebrates were limited to a very small number of midge larvae which are generally the primary colonizers. Zooplankton levels were similarly low with a few cladocerans (Daphnia pulex) appearing in the fall survey. Phytoplankton diversity was surprisingly high but densities very low despite high nutrient levels; the limited light penetration in the turbid water resulted in low Chlorophyll A values.

The second survey (Pisces 1989) was conducted during the spring and fall of 1988. The lake had reached full supply level and outflow commenced on October 6, 1987. By June 22, 1988 water clarity was excellent with Secchi disc transparency to 4.1 m (13.5 ft). No further turbulence was observed; the weight of the water and the deposited sediment has apparently sealed the coal from further methane release. Thermal stratification was apparent at 8-9 m (26-30 ft) with oxygen depletion at depths below 15 m (50 ft). Phosphorous levels had significantly decreased to well within Alberta Surface Water Quality Objectives but nitrogen remained high. This is a common situation at the minesite and is a result of the use of Ammonium Nitrate/Fuel Oil as a blasting agent. Providing phosphorous continues to be the limiting factor, high nitrates were not considered a problem and would likely contribute to a more productive alpine lake. Phytoplankton density was much improved and is now comparable to natural lakes in the area, however, diversity was reduced from the previous survey with Coccochloris sp., the dominant genus. Zooplankters were again predominantly Daphnia pulex. It was interesting that the percentage of these individuals greater than 1 mm in length increased from less than 10% in June, to 33% in September, to 97% in January of 1989. Total biomass was estimated at 0.495 mg/lit. Dipteran populations had dramatically increased since the initial survey, however, with the exception of a few valvatid snails, they were the only benthic invertebrates represented.

The 50-B-6 Lake has demonstrated substantial improvement in water quality and biological productivity over the past two years. Although final fishery success will be restricted by the limited littoral zone available, the proposed end use of a recreational fishery is achievable. Further improvements may be implemented to speed the establishment of the biological community.

Future Plans

Physical enhancements in the 50-B-6 Lake area are very near completion. Soil material will be placed and seeded in a small section at the west end and a maintenance fertilization program on the revegetated areas will be carried out. One further idea which will be investigated is the installation of a pipeline operated during the summer seasons to siphon deoxygenated water from the profundal zone and release downstream. This would serve to reduce the volume of productive water lost to outflow resulting in an increase in above-thermocline temperatures and a deeper oxygenated zone.

A number of biological improvements will be implemented through the summer of 1989. Additional volumes of particially decomposed hay will be placed in the littoral zone at the lake outflow. As a result of the apparent success of last years program, further macrophyte transplants will be undertaken. Transplants of benthic invertebrates will also be conducted, focussing on amphipods such as Gammarus lacustris and Hyalella azteca which are easily accessible in local ponds and lakes. Consideration is also being given to the introduction of Opossum shrimp

(Mysis relicta) which is indigenous to deep cold lakes and can be an important food chain component in a trout fishery.

In an attempt to diversify and intensify the phytoplankton population, water will be taken from a local lake and stored in the sunlight in a transparent tank. Light additions of water soluable fertilizer and aeration over a 4-6 day period should produce a good introductory stock for release to the lake. Controlled phosphorous applications to the lake itself will then encourage population expansions within the waterbody.

Fish stocking is currently scheduled for 1989 and will supplement the influx of native Rainbow (Salmo gairdneri Athabasca), Brook Trout, and Dolly Varden (Salielinus malma) which have moved upstream from the Macleod River System. Estimates for annual fish production potential range from 1.90 to 8.75 kg/ha (1.69 to 7.79 lb/ac) which favourably compares to the average of 6.5 kg/ha (5.79 lb/ac) for 46 high mountain lakes in Alberta (Radford 1979). In the 50-B-6 lake, cladocerans over 1 mm (0.04 in) in length formed the bulk (>85%) of available fish food. This source would be most efficiently utilized by Cutthroat trout (Salmo clarki), however, local Fish and Wildlife authorities indicate a preference toward the native Rainbow to prevent hybridization of this strain. The presence of Brook trout and Dolly Varden in Jarvis Creek West may suggest the genetic purity has already been compromised. Initial stocking rates for Rainbow would be in the range of 75-85 fingerlings per hectare (30-35 per acre) with cautious maintenance stocking until natural reproduction rates can be evaluated.

Public access will be permitted by 1992 provided future monitoring of the lake confirms viable fishery production. A foot or ATV access initially will prevent overfishing and immediate depletion of the stocked population.

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UTILIZATION OF OFF-CHANNEL DREDGE PONDS TO INCREASE JUVENILE CHINOOK SALMON REARING HABITAT[1]

by

Carl Richards[23], Phillip J. Cernera[4], Mike P. Ramey[5], and Dudley W. Reiser[6]

Abstract. The Yankee Fork of the Salmon River, Idaho, historically supported large runs of anadromous salmonids, primarily spring chinook salmon and steelhead trout. These runs have been dramatically reduced in the last 20-25 years due to localized mining activities and the effects of downstream hydroelectric developments. The mining activities resulted in the complete rechanneling of portions of the Yankee Fork and the deposition of extensive unconsolidated dredge piles which degraded much of the rearing and spawning habitat in the Yankee Fork. Fisheries studies indicated that chinook salmon smolt production in the Yankee Fork is limited by the availability of rearing habitat, and as a result, enhancement efforts were focused on ways of increasing or improving available rearing space. The river is bordered by over 30 ponds of varying size, shapes, and depth, that are remnants of the dredging operation. Most of the dredge ponds are off-channel and have no direct surface connection with the main channel. Engineering concepts were developed that focused on connecting off-channel dredge ponds to the river thereby increasing usable rearing habitat. Four series of dredge ponds were constructed, each containing 2 to 7 ponds connected in series. Inlets and outlets to the ponds were designed to allow easy access by juvenile chinook salmon. Incorporation of these dredge ponds to the Yankee Fork has increased the rearing capacity of the Yankee Fork river by 24,000 smolts.

Additional Key Words: Oncorhynchus tshawytscha, habitat preference, supplementation, habitat enhancement

Introduction

Historically, the Yankee Fork of the Salmon River in Idaho historically supported large spawning populations of anadromous salmonids, primarily chinook salmon (Oncorhynchus tshawytscha) and steelhead trout (Oncorhynchus mykiss). These runs have been dramatically reduced in the last 20-25 years due in part to localized mining activities, and downstream effects associated with hydroelectric developments.

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Past dredge mining activities in the stream channel and adjacent floodplain resulted in the complete rechanneling of lower portions of the Yankee Fork and the deposition of large unconsolidated spoil piles. Such mining activities eliminated or degraded much of the rearing and spawning habitat in the lower Yankee Fork. As a result, the Yankee Fork drainage is under-utilized with respect to salmon and steelhead production. Without the replacement or enhancement of this habitat, salmon and steelhead production potential in the drainage will remain below historic levels.

The Shoshone-Bannock Indian Tribes have treaty guaranteed anadromous fishery rights outlined in the Fort Bridger Treaty of 1868 and continue to fish the Yankee Fork when excess fish are available. Through their concern for this resource, the Tribes sponsored a habitat enhancement effort in the drainage in order to develop a sustained harvestable fishery. Funding was provided by Bonneville Power Administration under the auspices of the Northwest Power Planning Council's Columbia River Basin Fish and Wildlife Program (Anonymous 1987).

Prior studies (Konopacky et al. 1986, Reiser and Ramey 1988, Richards and Cernera 1988) indicated that the quantity of rearing habitat was limiting to spring chinook salmon populations within the river. These studies also documented the quantity and quality of fisheries habitat throughout the drainage. Enhancement efforts were therefore focused on increasing rearing habitat for juvenile salmon.

As a result of mining, numerous dredge/settling ponds were left as isolated aquatic habitats scattered among the spoil piles. These ponds were of varying sizes, depths and location in respect to the main river channel. Most of the ponds lacked direct surface connection to the river and therefore were not utilized by chinook salmon. Data obtained from engineering and fisheries studies resulted in a plan to connect some of these ponds to the river thereby augmenting the available juvenile rearing habitat in the basin. The purpose of this paper is to describe the general methodology used in connecting the ponds to the river and document fish utilization of the pond habitat.

Study Area

The Yankee Fork River is a major tributary to the upper Salmon River and is located in Custer County, Idaho within the Challis National Forest. The Yankee Fork is a medium-gradient system which flows through narrow canyons and moderately wide valleys of lodge pole pine (Pinus contorta) and Douglas fir (Pseudotsuga menziesii) forests. The upper portion of the Yankee Fork and its major tributary, West Fork, provide excellent spawning and rearing habitat for spring chinook and steelhead trout. A 9.6-Km stretch of the lower portion of the Yankee Fork river between Jordan Creek and Polecamp Flat, flows through an area that was extensively dredge mined for gold in the 1930's and 1950's. Currently this section of river is characterized by relatively wide, straight channels dominated by boulder and cobble substrate. Channel banks are sparsely vegetated and long sections contain no riparian zones. The river is bordered by over 30 ponds of varying size, shape, and depth, that are remnants of the dredging operation (Figure 1).

Methods

Development of Ponds as Off-Channel Rearing Habitat

Both in-channel and off-channel development of additional rearing habitat were originally considered as possible options. A brief comparison between the benefits and cost of the two alternatives suggested that the development of the off-channel ponds provided the greatest benefit at the least cost (Reiser and Ramey 1987).

Aerial photographs and U.S.G.S. topographic maps of the mined area were used to aid in the selection of ponds which would be amenable to development. Four distinct series of ponds were selected. A detailed field survey of the four ponds series was performed which provided ground topography and pond water surface elevations. Numerous spot pond depth measurements were taken and combined with pond surface area in order to quantify the available habitat. Water quality samples were obtained from several of the ponds to assure that the water would provide acceptable rearing habitat for juvenile chinook. Tests were performed for dissolved oxygen, water temperature, conductivity, turbidity, and heavy metals.

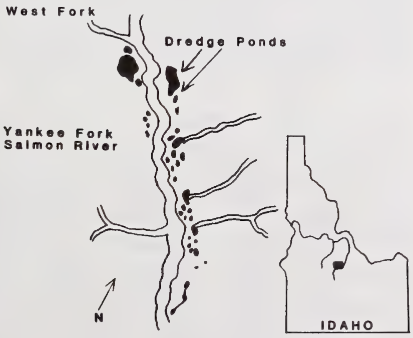

Figure 1. Location of dredge ponds along the Yankee Fork of the Salmon River.

Engineering concepts for the four pond series entailed interconnecting all ponds within each pond series with channels. Inlets and outlets for each pond series to and from the Yankee Fork River were then provided. The plan and profile of a typical pond series is shown in Figure 2. An intake structure at the upstream end of each pond series provided a means to control flow into the ponds. In addition, flow control structures, constructed of redwood, were placed at the downstream end of most ponds for water level controls. The dredge-mining left behind a highly permeable valley floor and ground water echange occurs between the ponds and the river. Consequently, the flow control structures were designed with adjustable weirs to give some flexibility in operating and adjusting the flow through the ponds. Flow control structures provided flexibility in the operation and management of the ponds. The interconnecting channels were designed to provide good rearing habitat while dissipating the necessary flow energy. The alignment, shape, and substrate of the channels were adjusted to a natural, stream-like appearance. Considerable effort was expended in the placement of boulders in the channels in order to improve the available rearing habitat and to minimize any potential migration barriers into and among the ponds. The opening of the ponds to the river created about 4 acres of pond habitat along with about 2000 feet of channel habitat.

Pond Series 1 has a total of five ponds. Due to the location of these ponds with respect to the Yankee Fork River, it was not feasible to provide an inlet to the pond series. Consequently, the ponds series outlet is the only access to and from the Yankee Fork. This pond

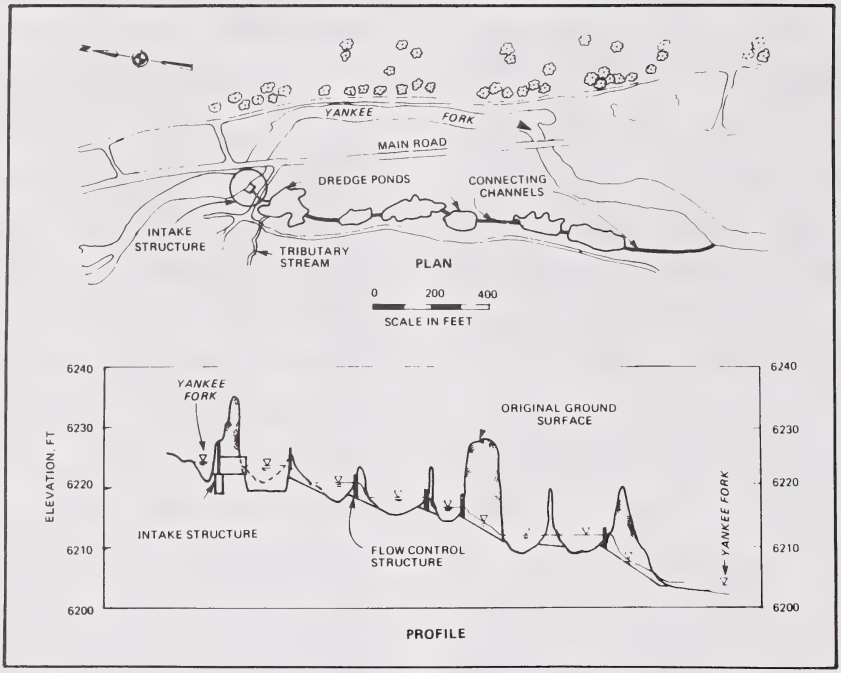

Figure 2. Plan and profile of pond series 2.

series presently relies entirely on groundwater flows for its water supply. A culvert beneath the main road connects this pond series to the Yankee Fork. A smaller pre-existing culvert was replaced to facilitate access of the juvenile salmonids to the ponds via the outlet.

Pond Series 2 has six ponds and a total length of about 485 feet. A small stream discharges directly into the uppermost pond resulting in water levels in some ponds to be about 0.6 m above the adjacent Yankee Fork level. Several Alternatives were considered for connecting the pond series to the river. The selected alternative entailed directly connecting the uppermost pond to the Yankee Fork thereby lowering pond level to river level. The pond was dredged to approximately the same depth as before the connection was made. Alternatives of connecting the ponds to a point farther upstream along the Yankee Fork were less desirable due to topography considerations and reduced accessibility by juvenile salmonids.

Pond series 3 has three ponds totaling about 545 m in length. The intake structure is located 45 m from the river which makes it less susceptible to damage during high flows. A small pool between the river and the intake structure acts as a sedimentation basin reducing the sediment load into the pond series.

Pond Series 4 also has three ponds, one of which 0.24 hectares in size. The original design concept utilized a large perforated pipe buried beneath the Yankee Fork to supply sediment-free water to the pond series. Prior to implementation, this concept was altered to a surface water withdrawal so that migrating salmonids can access the pond series through both the inlet and the outlet.

Fisheries Studies

Although juvenile salmon typically prefer relatively slow moving water associated with cover similar to that found in the ponds (Lister and Genoe 1970, Everest and Chapman 1972), the size, shape, and biological characteristics of the ponds differed from what is typically found in the mainstem Yankee Fork. The ponds were larger and with flows reduced compared to the pools and backwaters associated with the river. Available cover was primarily aquatic vegetation instead of river cobble and woody debris. Overhead cover was virtually non-existent in pond series 3 and 4. Due to these differences, pond microhabitat and fish utilization of this habitat was determined to provide a greater understanding of how best to operate and maintain the pond series. These investigations were conducted in pond series 3 and 4.

Pond shapes were traced on graph paper from 1:24,000 air photos. Available habitat types within each pond series were assessed by ground survey and delineated on the pond maps. Habitat types were based on; proximity of habitat to the bank or to open water, the depth of that habitat (<1m=shallow, 1m or >=deep) and cover availability. Cover components included; boulders, woody debris, macrophytes and algal mats. The total area of each individual habitat type was summed to determine total area per pond series. Area measurements transposed from air photos were verified by ground survey of representative pond sections.

Table 1. Habitat classification in pond series 3 and 4.

	Pond Series 3		Pond Series 4	
Habitat Type	Area(m^2)	%	Area(m^2)	%
Bank/Shallow/No Cover	505	15.4	349	12.3
Bank/Shallow/Cover	419	12.7	167	5.8
Open/Deep/No Cover	67	2.0	287	10.1
Open/Deep/Cover	658	20.0	1501	52.7
Open/Shallow/No Cover	349	10.6	84	3.0
Open/Shallow/Cover	656	19.9	117	4.1
Bank/Deep/Cover	167	5.1	58	2.0
Bank/Deep/No Cover	103	3.1	8	0.3
Channel/Cover	285	8.7	278	9.7
Channel/No Cover	81	2.5	0	0
*Bottom with Algae	1900	57.8	1843	64.7

*Bottom with Algae= summation of habitat types 2, 4, 6, and 7

On June 1, 1988, 27,000 and 23,000 juvenile chinook salmon were released in pond series 3 and 4, respectively. Fish habitat utilization was determined during the latter part of each month in each pond series from June through August. Fish were counted by divers equipped with snorkel and mask (habitat types 1 through 8), seineing (habitat type 11) and electrofishing (habitat types 9 and 10) (Table 1). All snorkeling and electrofishing were initiated at the downstream most section of the pond series and continued progressively upstream.

Data on fish populations were obtained by electrofishing (DC) in representative sections of channel habitat within each pond series. Block nets were set at the upper and lower ends of the area to be sampled and the area was shocked. A multiple step removal depletion method (Zippin 1958) was used to estimate abundance. In addition, seine hauls (10 x 1m, 5mm mesh leaded line) were made in representative sections of vegetated pond bottoms of known area. These areas were unsuitable for electrofishing or direct observation.

In several small shallow ponds that lacked cover, fish were counted by one person equipped with polarized lenses observing fish from the bank. In all other ponds, fish were enumerated by divers equipped with snorkel and mask. When pond widths were narrow enough to allow underwater observation of both banks from the center of the pond, one diver would approach the downstream end of the pond and slowly swim north, noting presence of fish and the habitat type in which they were seen. In wider pond segments, two divers would enter the downstream end of the pond segment and swim upstream parallel to each other in "lanes" (Platts et al. 1983). Each observer counted fish in his lane only. Lane width was dictated by underwater visibility (the maximum distance at which we could recognize an object the size of the smallest fish). Divers positioned themselves about 1m ahead of the other. This facilitated the counting of any fish that tended to move laterally. Using this technique, diver counts would include all fish present from the bank out to the center of the pond. In extremely large sections of certain ponds, after the divers moved upstream for a known distant, they would leave the bank and swim (noting fish) in a lane across the open body of water to the other side of the pond.

Results

Microhabitat Evaluation

Eleven different microhabitat types were observed and delineated (Table 1). In both pond series, benthic habitat with an algal-mat cover (habitat type 11) encompassed the largest percent of the overall pond habitat. This habitat was actually the summation of several other micro habitats (Table 1). Open deep water with cover was the predominant single habitat type found in both pond series. Open deep water with no cover was the least available habitat in pond series 3. No channel habitat without cover was found in pond series 4.

Habitat Utilization

Age 0+ chinook density estimates for ten of the eleven habitat types were lumped into 3 basic habitat groups; bank, open water or channel. Each of these habitat types was further divided into those with and without cover. Sampling periods and pond series were combined in order to observe general trends.

Table 2. Mean densities of juvenile chinook salmon in pond series 3 and 4.

Habitat Type	Cover Present	fish/m^2	SD	n
Bank	No	0.14	0.36	35
	Yes	0.18	0.43	27
Open Water	No	0.12	0.36	21
	Yes	0.31	2.90	59
Channel	No	0.0	0.0	3
	Yes	6.26	6.30	10

Initial densities of juvenile chinook salmon were 0.12 fish/m^2 and 0.11 fish/m^2 in pond series 3 and 4, respectively. Fish however, did not disperse evenly throughout the ponds. In general, throughout the course of the summer, densities were greater in all habitat types when cover was available (ANOVA, $\underline{p}<0.05$). Densities ranged from 0.12 fish/m^2 in open water that did not have cover to 6.26 fish/m^2 in channel habitat with cover (Table 2).

Total abundance of fish in each of the six habitat types was estimated by extrapolating mean density on the total area of the habitat. These values (expressed as percent of total) were then compared with habitat availability to determine if distinct habitat preferences existed (Figure 3). A definite preference was noted for channel habitat in and between the ponds in both pond series. Even though this habitat represented a relatively small portion of available habitat, a large portion of the total number of fish were found there. No other distinct preferences were observed. Fish appeared to avoid shallow water without cover in both pond series since the proportion found in this habitat was considerably smaller than the proportion of habitat available.

In both pond series 3 and 4, open water with and without cover comprised the largest percent (>55%) of the overall pond habitat. In pond series 3, this habitat was utilized by a correspondingly large percent (>50%) of the juvenile chinook. In pond series 4, however, open water habitats were utilized by less than 15% of the total number of fish. This would indicate some avoidance of open water habitat in pond series 4. The reason for this avoidance in pond series 4 may be related to the large size and depth of habitat available in the series. Most habitat in pond series 4 is located in one large deep pond. Pond series 3 has a larger number of smaller ponds.

Discussion

The addition of the pond habitat to the mainstem Yankee Fork River was an effective means of adding considerable rearing habitat for chinook salmon. Over 4 acres of habitat suitable for juvenile chinook was added by connecting ponds to the river through the excavation of channels and construction of check structures to control surface flows.

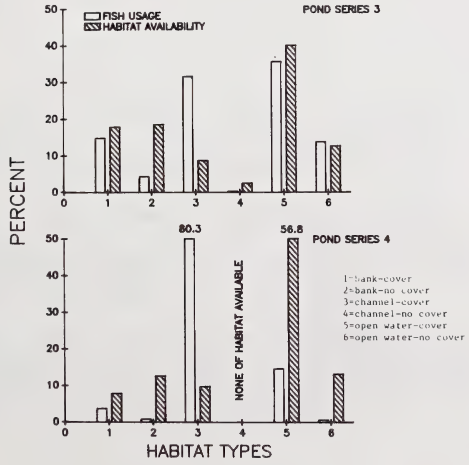

Figure 3. Habitat availability and fish habitat preference in pond series 3 and 4.

Fish distributions in the ponds during the summer of 1988 indicated juveniles would use available habitat although some preference was demonstrated for specific microhabitats within the ponds. The strong preference indicated for channel habitat may be due to rearing history of the fish in the hatchery. The fish were reared at high density in flow-through concrete channels that were most similar to channel habitat in the ponds. Habitat selection by these fish may have been somewhat different than their wild counterparts.

Since microhabitats with cover available in the form of woody debris, boulders and algae were preferred over similar habitat without cover, the ponds could be improved through the addition of cover. Small cedar or other available cut trees and branches could be placed in shoreline areas of the ponds to increase suitability for juvenile habitat. Addition of physical cover might also increase the quality of habitat in deep water areas.

The use of check structures at strategic locations in the pond series allows for alternative fish management strategies. Although the ponds were designed to provide easy access and full utilization by natural spawning populations of chinook salmon in the Yankee Fork, they may also be used as stocking points for hatchery releases of fingerlings. Large reductions in population size are often observed immediately following stream releases of chinook salmon (Richards and Cernera 1988). Pond habitat may provide a more suitable habitat for release of hatchery-reared fingerlings than more typical stream habitat. With relatively minor modifications, the ponds could also be adapted for use as low-tech rearing facilities (Reiser and Ramey 1988). Automatic feeding stations could be added to some of the ponds and movement of fish between ponds could be controlled with barriers so that much higher densities of juveniles could be reared than is possible through natural production.

Use of the off-channel dredge ponds for juvenile chinook rearing habitat provides a variety of fisheries management options in the drainage. Although riparian and other stream habitat lost during mining activities will never be fully replaced, the additional rearing habitat can provide partial compensation for this loss in relation to fish production.

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WILDLIFE HABITAT MITIGATION FOR THE OLDMAN RIVER DAM PROJECT, ALBERTA, CANADA[1]

by

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and

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Abstract. To compensate for losses of wildlife habitat associated with the construction and operation of the Oldman River dam in southern Alberta, an extensive wildlife habitat mitigation program has been undertaken. Habitat evaluation procedures were used to determine the amount and types of habitat losses in the reservoir area, and the most important habitat needs of wildlife in the mitigation program. Three major types of mitigation, involving thirteen specific measures, are being employed in the Mitigation Program: habitat protection, habitat enhancement and habitat creation. A concept plan was developed that addressed the biological requirements of wildlife (e.g., movement corridors, core habitat areas and other specialized sites) in conjunction with existing land uses, the need for a good distribution of projects around the reservoir, and the suitability for establishment of woody vegetation. In total, 65 habitat projects are being developed, as well as additional projects for cliff nesting raptors. Other habitat enhancement and creation projects may be developed as opportunities arise during dam construction and reclamation.

Additional Key Words: habitat reclamation, mule deer, waterfowl

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Introduction

The Oldman River Dam is currently being constructed a short distance downstream from the confluence of the Oldman, Crowsnest and Castle rivers in southern Alberta. When completed in 1990, the dam will create a reservoir covering an area of approximately 2420 ha at full supply level (FSL). Figure 1 shows the location of the reservoir.

Although cultivated fields, pastureland, winter feedlots and farmsteads occupy most of the bottomland areas in these valleys, the remaining valley areas and adjacent coulees are important overwintering habitats for wildlife. For example, approximately 350-400 mule deer (*Odocoileus hemionus*) overwintered in and around the

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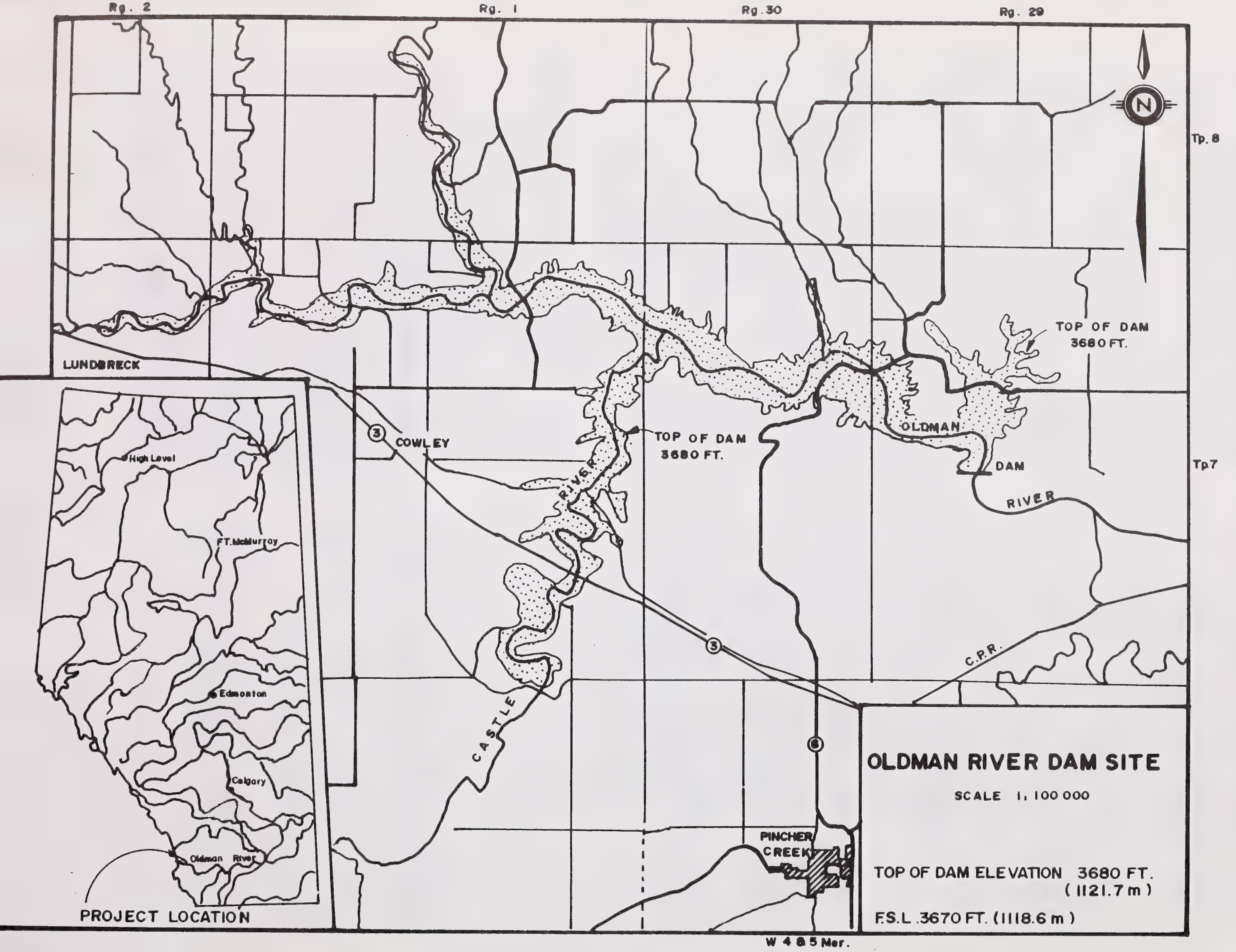

Figure 1. General location of the study area for the Oldman River Wildlife Habitat Mitigation Plan in southeastern Alberta, Canada.

reservoir area during 1985-86, with slightly more than half that number being present during the spring and summer months (Allison and Russell 1986). The reservoir area also supports a variety of other mammals and avifauna on a seasonal or year-round basis including white-tailed deer (*O. virginianus*), moose (uncommon) (*Alces alces*), yellow-bellied marmots (*Marmota flaviventris*), badgers (*Taxidea taxus*), beaver (*Castor canadensis*), mink (*Mustela vison*), Ferruginous hawks (*Buteo regalis*), prairie falcons (*Falco mexicanus*), Canada geese (*Branta canadensis*), mallards (*Anas platyrhyncos*), and common mergansers (*Branta merganser*) (Young et al. 1986).

Because of the importance of the flooded area to wildlife, Alberta Public Works, the Alberta Fish and Wildlife Division and Alberta Environment have undertaken a program to enhance existing habitat conditions around the proposed reservoir. The Delta Environmental Management Group Ltd. (The Delta Group) was retained to develop practical, effective habitat improvement and creation projects which could be implemented in the vicinity of the reservoir area during 1988 to 1993 (Green and Eccles 1988; Nilson and Green 1988). Recent studies on wildlife numbers, distributions and habitat preferences in the vicinity of the Oldman River Dam (Allison and Russell 1985, 1986; Westworth 1984; Young et al. 1986), as well as information from the Alberta Fish and Wildlife Division, the Local Advisory Committee, and field surveys, aided in the selection and design of appropriate projects for the area.

The major objectives of the Wildlife Habitat Mitigation Plan, as described by Alberta Environment (1988) are:

1. To minimize the potential negative impacts of the Oldman River dam project on wildlife species, and
2. To take advantage of mitigation opportunities arising from the development of the dam and reservoir.

This paper describes the major measures which will be implemented as part of the Wildlife Habitat Mitigation Plan with emphasis on specific wildlife considerations relating to the water level fluctuations of the Oldman River Dam Reservoir.

Habitat Mitigation Projects

The wildlife habitat mitigation program involves three major classes of mitigation methods: habitat protection, habitat enhancement and habitat creation.

Habitat Protection Measures

Two initiatives have been undertaken to complete the habitat protection phase of the wildlife habitat mitigation program. A land base of approximately 700 hectares (2300 acres) has been secured from crown lands for use in the wildlife habitat mitigation program. An additional 50 ha of private land may be secured through easements, leases or purchase agreements to complete the wildlife mitigation program.

1. Vegetation clearing guidelines have been established to retain as much habitat as possible. These include:
    - staging the clearing of the reservoir over 1989 and 1990 to delay disturbance of wildlife cover as long as possible;
    - retaining most shrubs of less than 3 metres in height within the flood zone of the reservoir;
    - preserving stands of black (*Populus trichocarpa*) and narrow leaf (*Populus angustifolia*) cottonwood and flood tolerant shrubs in those areas of the reservoir where only shallow flooding (i.e., <2 m) of short duration (e.g., <5 weeks) is expected to occur during the normal operation of the reservoir, or where soil erosion will not threaten moderate to long-term (>25 years) survival of trees and shrubs. This also includes leaving selected stands of vegetation within the borrow areas downstream of the dam.
    - minimizing the clearing of Douglas Fir (*Pseudotsuga menziesii*) and trembling aspen (*Populus tremuloides*) communities in the area between the full supply level and the reservoir takeline; and
2. All of the land base for wildlife will be fenced to permit management of grazing and other land uses utilizing a 3-wire fence with posts at 5 metre spacing. Fencing of the wildlife mitigation land base will add 7 km of fence to the 118 km fence that is required for the reservoir boundary.

A range management program will be developed for suitable areas of native and improved pasture that occur within the fenced boundaries of wildlife habitat mitigation projects. Range management plans will identify acceptable standards for cattle use (e.g., the number of animal use days, timing and duration of use), and recommend rest-rotational grazing schemes (e.g., location of water sources, additional fencing as necessary) to permit cattle use without detrimental effects to wildlife habitat. Gravelled water access will be provided to most check dams in the vicinity of existing private or crown owned pasture lands.

Operation and maintenance of this portion of the program is limited to the maintenance of the fence and the administration of the grazing permit system.

Habitat Enhancement Measures

Habitat enhancement projects involve the improvement and/or expansion of existing sites and natural habitats to provide more suitable and/or larger areas of habitat for terrestrial and wetland wildlife than presently exists. Habitat enhancement includes:

1. A total of 25 km of snowfence will be installed along the perimeter fence and/or within the land base of 31 projects. Snowfencing will locally improve soil moisture conditions (as a result of increased snow retention) and reduce exposure to wind. It will also encourage the expansion of native trees and shrubs up and out of the existing coulees, and aid in the establishment of planted shelterbelts. Irregularly-shaped shelterbelts comprised of upland species of trees and shrubs such as trembling aspen, chokecherry (*Prunus virginianus*), saskatoon (*Amelanchier alnifolia*), hawthorn (*Crataegus rotundifolia*) and Douglas fir will be planted immediately adjacent to the leeward side of the snowfencing in almost all projects. As native tree and shrub communities expand and the planted shelterbelts become established, snow catchment will increase, thereby reducing the future need for snowfencing. As a result, long-term maintenance of snowfencing will not be required.
2. Five existing wetland areas will be enhanced for waterfowl through stabilization of water levels (including the provision of supplemental water supplies during periods of poor water availability), construction of earthen or rock nesting islands in the central deep water areas of wetlands, enlargement of the wetland basin, planting of riparian shrubs and trees along some portions of the wetland shoreline, reseeding of nesting cover in adjacent upland areas, and/or maintenance of existing nesting cover.
3. Nine nesting sites for Canada geese will be constructed on several outcroppings that are likely to become large islands within the reservoir. Nest sites will include one or more log nest cribs and, in some cases, may include planting of small shelterbelts and erection of snowfencing.
4. Native and improved range in several areas within the takeline is in poor condition or has been removed by cultivation. These areas will be reseeded with native or suitable commercially-available grasses to provide a stable grass cover for control of noxious weeds and soil erosion, as well as forage for wildlife and cattle. Some pasture areas will be fertilized to promote rapid regeneration of ground vegetation.

All of the enhancement projects are within the fenceline provided for the habitat protection measures. Although short term maintenance will be required for establishment of aquatic and riparian vegetation in enhanced wetlands, tree and shrub establishment for nesting cribs, and range reseeding programs, no moderate or long term maintenance (i.e., >5 years) of these projects will be required. However, a process for administration and management of grazing permits within the wildlife mitigation areas will be implemented.

Habitat Creation

Habitat creation projects involve the construction or significant modification of existing sites to provide habitats with significantly different biological and physical conditions than existed previously. Habitat creation project will include:

1. The accumulation and storage of water in check dams and newly-created wetlands, and the distribution of water in the areas where soil moisture conditions may limit the initial establishment of tree and shrub cover. The accumulation and storage of water and the ability to provide water to the newly-planted seedlings on a frequent basis is essential to

the successfully establishment of new tree and shrub cover in exposed upland areas.

Water storage structures will range from dugouts with shallow catchment basins to small (<7 m in height) dams in several coulees. In areas where sufficient natural runoff exists to provide a two year supply of water, no ancillary measures are necessary. Where the natural runoff is insufficient, supplementary water will be provided by shelterbelts to improve and/or concentrate snow catchment, subsurface drainage to capture artesian springs, and pumping of water from the Oldman reservoir using electric, solar or wind powered systems.

Stored water will primarily be used to water tree and shrub seedlings that are located downstream of the check dams and dugouts, using subsurface irrigation tubing with slow release emitters. Methods are currently being investigated to automate the operation of these irrigation systems. Water levels in the check dams and dugouts will fluctuate seasonally in response to snowmelt and rainfall, evaporation, water removal for watering of trees and shrubs, and livestock use. In two locations, check dams will be used to maintain stable water levels in newly-created wetland basins. Riparian shrubs and emergent aquatic vegetation will be planted along the perimeter of most check dams and dugouts to provide vegetation cover and food for terrestrial and wetland wildlife. Thirty-one (31) check dams and dugouts are proposed.

2. New riparian habitat will be provided through the construction of terraces and/or dikes within the upper flood zone of the reservoir (i.e., up to 3 m below full supply level). Riparian wetlands will be constructed at 23 locations. These sites will backflood when the reservoir is brought to full supply level, and hold water 0.6 m below the full supply level of the reservoir when it is lowered. Where appropriate, nesting islands for waterfowl and Canada geese will be constructed in these wetlands. Narrow leaf cottonwood, sandbar willow (*Salix exigua*), sedges (*Carex* sp.) and aquatic plants will be planted in the area immediately at and below full supply level. Riparian trees and shrubs such as black cottonwood, sandbar willow, red osier dogwood (*Cornus stolonifera*) and white spruce (*Picea glauca*) will be planted in the areas immediately above full supply level. The proposed riparian wetland projects will replace some of the bottomland habitats that will be lost to flooding, and will provide several core habitat areas.

3. Fifteen new nesting cavities for prairie falcons and Ferruginous hawks have been constructed on cliffs above the full supply level of the reservoir or on cliffs adjacent to the reservoir edge (i.e., up to 2.0 km away from the reservoir) using controlled blasting, manual digging and prying. New nesting ledges for Canada geese have also been constructed on cliffs directly adjacent to the reservoir. Although constructed in January 1989, two nesting cavities are already being used by prairie falcons and several ledges have been used by Canada geese and great horned owls.

4. On the request of the local wildlife advisory sub-committee, two marmot colonies that are presently located in the reservoir area will be transplanted to new locations above full supply level. In one case, a rock pile will be constructed adjacent to suitable foraging habitat to provide a suitable core area for burrows and loafing/observation sites.

In general, new habitat projects will be the most difficult to establish and most will require an operations and maintenance commitment. The proposed check dams and dugouts will require annual inspection and maintenance to ensure their serviceability, stability and safety. Although the subsurface irrigation systems will be automated, routine inspections will be required to ensure operation. It is anticipated that all irrigation systems will be operated for a minimum of 5 years to allow trees and shrubs to become well established, thereby creating a micro-climate that is self-sustaining. Operations manuals and spare parts will be provided for the operations personnel to operate, maintain and inspect these mechanical systems at appropriate intervals.

Implementation Schedule

Completion of the wildlife mitigation program will be constrained by several project activities including:

- the filling schedule for the reservoir,
- attainment of a full operational level for the reservoir, and
- propagation of native tree and shrub stock.

However, as the land base has already been secured for the wildlife habitat mitigation program, most aspects of the mitigation projects involving construction of facilities, excavation, recontouring, and fencing can be completed during the 1987 - 1989 period.

Plantings of trees and shrubs will primarily utilize native species from the Oldman River region. To provide stock that is already conditioned to the biophysical conditions in the Oldman River area, cuttings and seeds of trees and shrubs were collected during the spring and summer 1988 and 1989 for propagation of containerized seedlings, bare root seedlings and cuttings. Species being grown include Douglas fir, limber pine, trembling aspen, black cottonwood, narrow leaf cottonwood, chokecherry, sandbar willow, saskatoon, hawthorn, red osier dogwood, buckbrush (*Symphoricarpos occidentalis*), snowberry (*S. albus*), and cinquefoil (*Potentilla fruticosa*). Most of these species will be available for planting in 1990 and 1991.

As the full supply level of the reservoir may not be achieved during the first year of operation (1991), the riparian marshes may not be backflooded from the reservoir until full supply level is attained. As a result, water may need to be provided and maintained by pumping water from the rivers or reservoir. Provision of water in these areas will permit the planting and establishment of riparian trees and shrubs and aquatic vegetation in and around the perimeter of these riparian wetlands, prior to full operation of the reservoir.

Several activities will be ongoing after 1991, including:

- Planting of remaining tree and shrub seedlings (predominantly those species that were not ready for planting in 1991).
- Maintenance of vegetation will continue until trees, shrubs and ground covers are well established.
- Reclamation activities in borrow sites and construction areas will continue as necessary.
- Remedial measures to specific mitigation projects or project components to ensure adequate wildlife habitat is established.

Monitoring and Evaluation

Physical, biological and botanical aspects of the program will be monitored after implementation to ensure the success, or the need for modification, of specific mitigation techniques.

The monitoring program will consist of three major components:

1. Assessments of Vegetation: Vegetation monitoring will include annual assessments of the survival of tree and shrub seedlings, surveys of ground covers in newly-seeded and/or fertilized pasture areas, inspections of transplanted and naturally invading aquatic vegetation in enhanced and newly-created wetlands and check dams, and range surveys in rest-rotational pasture areas. Vegetation monitoring will provide information on the establishment and response of native vegetation in the habitat projects and, in particular, will highlight the need for supplemental or replacement plantings of seedlings, ground covers and aquatic plants.

2. Assessments of Wildlife Distribution and Habitat Use: The wildlife monitoring component will require assessment of the response of wildlife to (i) the dam construction and clearing activities, and (ii) the habitat mitigation projects.

   Assessment of the responses of wildlife to the dam construction and clearing activities will require monitoring of changes in the abundance and distribution of several species and/or groups of wildlife that are representative of the habitat requirements of most wildlife in the Oldman River region. Recommended key wildlife species/groups include: mule deer, waterfowl, raptors, and songbirds. Proposed surveys include:

   - systematic surveys of mule deer populations in the vicinity of the Oldman River (in the vicinity of the project area) and in existing wetlands near the reservoir. Proposed surveys include an early spring breeding survey, brood counts, and a fall staging survey.

   - annual surveys of nesting and non-breeding prairie falcons, Ferruginous hawks and other raptors in the Oldman Project area. Data will also be obtained on the nesting success of prairie falcons and Ferruginous hawks in the immediate vicinity of the reservoir. Nesting prairie falcons have been colour banded to permit tracking of nesting pairs during and following dam construction, and the modification of nesting cliffs for these species.

- breeding birds counts for song birds and upland game birds in the reservoir area. Permanent survey blocks will be established in representative vegetation communities.

Baseline data are available for ungulates and raptors from wildlife surveys conducted in 1985 - 1986. Systematic surveys during dam construction will be conducted in mid-winter 1989-90 and 1990-91. Post-flooding surveys will then be conducted, at minimum, on a biennial basis.

Monitoring of the responses of wildlife to the mitigation projects will involve annual and biannual assessments of the use of representative habitat projects by key species and groups of wildlife. Although data from the surveys described above will be used, information will also be obtained on the use of tree and shrub plantings by ungulates (e.g., browse surveys, pellet group counts), and wetland use by waterfowl.

3. Audits of Habitat Projects: Habitat designs for specific projects will generally involve hydraulic structures (e.g., check dams, subsurface irrigation systems), physical structures (e.g., perimeter fencing, snowfencing), vegetation components, and/or specialized habitat structures (e.g., nest cribs, nesting ledges, nesting islands, rock piles). In combination, these project components should provide specific types of habitat for terrestrial and/or wetland-associated wildlife.

Audits of habitat projects will be used to determine if the habitat objectives of specific projects are being achieved, and that specific project components are performing as planned. Project audits will involve a combination of one or more of the following, depending on the complexity and scope of the habitat project:

- annual inspections of check dams and dugouts to assess water retention capabilities,

- annual inspection of subsurface irrigation systems to ensure that adequate water is being provided to tree and shrub seedings,

- annual inspections of barbed-wired fencing and snowfencing,

- seasonal inspections of rest-rotational pastures to assess range productivity, and to ensure compliance with the range management plan, and

- annual assessment of habitat suitability in representative habitat projects. Quantification of habitat suitability will require measurement of vegetation features, terrain features, and physical structures (data from the vegetation monitoring and wildlife monitoring programs can be used to assist in assessment of habitat suitability), and use of field data in computerized habitat assessment models.

Project audits will allow early identification and correction of project deficiencies or problems, as well as the potential to identify other habitat enhancement or creation opportunities.

The Glass Project

Prior to the completion of the Wildlife Habitat Mitigation Plan, a comprehensive wildlife development program was initiated on a 200 ha parcel of land immediately adjacent to the dam construction site. Referred to as the Glass Property, it is comprised of approximately 150 ha of previously cultivated land and 50 ha of native pasture. As a result of recent poor land management, 120 ha of the cultivated land has been subjected to extensive wind erosion. A series of well-established shelterbelts, running east-west and north-south, divide the northern third of the area into four distinct blocks. Two major coulee systems occur in the southern third of the property. Three natural wetland depressions are located in the west-central portion of the property, but because of the extended drought in the Oldman region, have been completely dry for at least the past two years.

Due to the proximity to the dam, the land will be permanently held by the Crown. Because of the land tenure, the need to restabilize eroding soils, and the existence of natural wetland basins and coulees, the Glass Property provided an excellent opportunity to integrate and test several wildlife habitat mitigation measures.

Water was considered to be the limiting factor in the initial establishment of tree and shrub cover on the property. Based on the previous experience of local landowners in establishing shelterbelts in similar exposed sites, it is essential that young trees and shrubs receive adequate moisture for a period of at least 3 to 5 years. Although tree and shrub plantings on the Glass Property were located on north-facing slopes, protected coulees and the lee side of snow fences whenever possible, direct watering of seedlings by subsurface emitter irrigation tubing was employed throughout most of the planting areas. Subsurface irrigation was chosen over truck watering because it is more cost effective, allows seedlings on slopes, can be fully automated in most circumstances, and in light of its lower operating cost, it is less susceptible to budget restrictions over the long term.

Construction of the prototype irrigation system began in fall 1987 and was completed in summer 1988. The system is comprised of a 15 HP electric pump to deliver water through an 8 cm diameter PVC pipe to a central control system on the Glass Project, and a network of water lines, control valves and 20 km of subsurface emitter tubing to provide a maximum of 0.5 - 2.0 gal/hr to each individual or pair of tree and shrub seedlings. The central control system is a mechanical timer that operates the control valves on specific water lines, and permits specific units of the irrigation system to be turned off and on in specific sequences over a 24 hour period. The exact duration and sequence of watering will be determined through trial operation in late June - early September 1989 and 1990. In other mitigation projects, a combination of emitter irrigation tubing and check dams will be used to provide an initial water source for seedlings.

The Glass Property is presently planted with commercial tree species: Northwest poplar, caragana (*Caragana arborescens*), blue spruce (*Picea pungens*), white spruce and willow. In addition, small native Douglas firs were moved from within the reservoir area to the Glass site to determine their success at transplanting and growing in a different aspect. Tree and shrub seedlings have been and will be planted in different configurations (contour plantings, straight rows, irregular groupings) to provide a diversity of cover and to assess the wind revetment characteristics of snowfencing (which has been erected close to most of the planting areas). The caragana and willow seedlings were spaced at 1 m, the Northwest poplar at 2 m and the blue spruce, white spruce and Douglas fir at 3 m. Rows of seedlings were generally spaced at 4 m or 8 m. A total of 27,000 seedlings have been planted to date. Of this total, approximately 17,000 seedlings will be moved to other sites around the reservoir (on an as-need basis). Native trees and shrubs will then be used to infill-plant in some locations on the Glass Property.

The Glass Property contains two natural wetlands, and two additional wetlands have been constructed in shallow depresssions. Bulrushes (*Scirpus* sp.) were transplanted as plugs from the reservoir area to one of the constructed wetlands to determine the success of this method. All four wetlands are now being filled from the pumping system, but the option exists to fill the wetlands, as required, by gravity from the reservoir. Snow entrapment by the snowfences and trees/shrubs will also provide a water source in the spring. Earthen islands for waterfowl nesting have now been constructed in two of the wetlands (one natural, one constructed).

The entire site was planted with a mix of agronomic grasses and legumes under a winter wheat cover during fall 1988 to reduce soil erosion and control weed cover. The mix is comprised of rough fescue (*Fescue scabrella*), sheep fescue (*F. ovina*), western wheatgrass (*Agropyron smithii*), streambank wheatgrass (*A. riparium*), alfalfa (*Medicago* sp.), and sweet clover (*Melilotus alba*).

Snowfencing has been used extensively (4.0 km in total) on the Glass Property to reduce the drying effects of wind on young seedlings, and to aid in the trapping of snow to improve soil moisture conditions in the spring and early summer. As the trees and shrubs become better established, they will further improve snow retention.

The Glass Property is currently used by mule deer and waterfowl.

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GRAZING DEMONSTRATION ON RECLAIMED LANDS AT THE BLACK THUNDER MINE, CAMPBELL COUNTY, WYOMING [1]

by

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Abstract. One of the standards of reclamation success is demonstrating the ability of the reclaimed plant community to sustain grazing pressure by domestic livestock and native wildlife that is at least equal to premining grazing pressure. Five to seven-year old reclaimed areas at the Black Thunder Mine were utilized in designing and constructing a two pasture rotational grazing system that encompasses a total of 74 hectares. The study design includes vegetation monitoring to document forage utilization and determine changes in vegetation due to grazing, and livestock weighing to determine animal performance while grazing mined land vegetation. In 1988, the first year of the study, Black Angus-Hereford cross (black-baldy) yearling steers were introduced to the west pasture in mid-May. The cattle were moved into the east pasture in mid-July where they remained until mid-September. Vegetation data were collected in mid-July and again in mid-September to provide baseline pasture vegetation characteristics and forage utilization data. First season results indicated excellent animal performance under 60-70% forage utilization, with average daily gains of 1.03 and 0.60 kilograms/animal/day during early and late rotations, respectively, and an average gain of 0.83 kilograms/animal/day season-long. Vegetation responses to grazing will be determined after post-grazing sampling in 1989 and 1990.

Additional Key Words: Revegetation, Cattle, Plant Response

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Introduction

Land use goals for most reclaimed surface-mined lands in Wyoming include establishment of stable self-perpetuating rangeland vegetation for support of wildlife and domestic livestock (Boles 1984). In terms of livestock grazing, revegetated lands must prove capable of both withstanding proper grazing pressure and meeting animal forage requirements (DePuit 1988, Laycock 1989).

Although protection of revegetated coal mined lands from grazing is legally mandated for at least the first two to three years of plant growth, grazing may be allowed in subsequent years to enhance certain aspects of the reclamation process (Boles 1984). For example, past research in the northern plains region has suggested a potential role of controlled grazing for improving vegetation productivity, changing plant species composition, increasing diversity, and/or accelerating carbon-nutrient cycling and pedogenesis (DePuit and Coenenberg 1989, Young and Rennick 1983). Furthermore, animal performance while grazing revegetated mined lands may provide one important indication of reclamation success from the standpoint of grazing utility (Sindelar and Murdock 1985, Ries and Hofmann 1984). For these reasons, incorporation of livestock grazing within operational reclamation programs is becoming more common at mines within the northern great plains region (e.g., Kleinman et al. 1984, Williamson 1981, Coenenberg 1982). Results of most demonstrations and research efforts have been positive, indicating that, with proper management, livestock can be successfully grazed on reclaimed lands with no adverse effects on vegetation or other site characteristics (Laycock 1989).

Although livestock grazing programs have been conducted at several Wyoming mines, most of the published information on mined land grazing in the region has been generated by studies in the surrounding states of Montana (e.g., Kleinman et al. 1984, DePuit and Coenenberg 1989, Young and Rennick 1983), North Dakota (e.g., Ries and Hofmann 1984, Hofmann and Ries 1988, Williamson 1981) and Colorado (e.g., Laycock and McGinnies 1985). An exception was the research of Schuman et al. (1986), which reported positive vegetation and animal responses under a three year season-long grazing regime on central Wyoming uranium mined lands. The fact remains, however, that a paucity of published information exists on mined land grazing within the Powder River Basin coalfields of northeastern Wyoming--the leading coal producing area of the northern great plains.

Objectives

A three year, two pasture rotational grazing demonstration was initiated in early 1988 on northeastern Wyoming coal mined lands revegetated primarily to a mixture of cool-season perennial grasses. The broad goals of this project are two-fold:

1. To determine the influence of the applied cattle grazing regime on productivity, structure and composition of vegetation, and

2. To evaluate the capability of established vegetation to support cattle under season-long rotational grazing, as determined by animal growth responses.

These two goals focus on key issues related to post-mining land use and management of this and similarly revegetated minesites in the area. If vegetation is demonstrated to adequately support livestock while either withstanding or benefiting from grazing use, it will be possible to state with a greater degree of certainty that reclamation objectives related to livestock production can be met with current technology. Conversely, if certain results prove negative, the need for and possible approaches toward improvements in reclamation methods will be clarified.

Methods and Procedures

Study Area Description

This study was conducted on a revegetated site at the Black Thunder Mine (Thunder Basin Coal Company) approximately 65 kilometers south of Gillette, Campbell County, Wyoming. Elevation of the mine ranges from 1408 to 1477 meters, and the climate is semiarid and continental. Annual precipitation averages 33 centimeters, most of which occurs as rain from April through July. Pre-mining vegetation is characterized by a mosaic of native rangeland plant communities, containing elements of both shortgrass and northern mixed prairie plant associations (Fisser et al. 1975). Specific plant communities are variously co-dominated by cool-season perennial grasses [e.g., western wheatgrass,(Agropyron smithii) and needle-and-thread grass, (Stipa comata)], warm-season perennial grasses [e.g., blue grama, (Bouteloua gracilis)] and shrubs [e.g., Wyoming big sagebrush, (Artemisia tridentata ssp. wyomingensis)]. The primary pre-mining uses of area rangelands involve support of wildlife (most conspicuously pronghorn antelope and mule deer) and grazing by cattle and sheep.

The specific study site occupies a previously mined and reclaimed area at the northeast corner of the mine (in Sections 9 and 16, T43N, R70W). After mining, spoils were graded to a varied topography (level uplands/lowlands, steeper slopes and drainages) and covered with 61 centimeters of topsoil. The site was drill seeded in the fall and spring of 1981, 1982 and 1983 with a mixture of native and introduced cool and warm season perennial grasses and fourwing saltbush (Atriplex canescens), at a rate of 22.4 kilograms PLS/hectare; the site was subsequently mulched with hay at 4484 kilograms/hectare. The site was fertilized with phosphorus (at 56 kilograms available P/hectare) in 1982 and nitrogen (at 56 kilograms available N/hectare) in 1983. By 1988, the site had become dominated (approximately 71% composition) by the seeded cool-season native grasses thickspike (Agropyron dasystachyum), western (A. smithii) and, secondarily, slender (A. trachycaulum) wheatgrasses. Crested wheatgrass (Agropyron cristatum), the only introduced species, was a co-dominant species (approximately 23% composition).

Grazing System Design/Implementation

Pastures. Two fenced pastures, one approximately 40 hectares and the other approximately 34 hectares, were constructed on the oldest reclaimed areas in the north pit (Figure 1). The fenced pastures include areas that were reclaimed in 1981, 1982 and 1983, as well as some drainage areas that were interseeded via hydroseeding in 1985. A livestock watering source was centrally located on the fence line that divides the two pastures. Water was pumped from a permanent impoundment to a 2000 gallon tank trailer which gravity fed a 1250 gallon livestock tank.

Livestock. In 1988, the pastures were grazed from mid-May to late September with 25 head of first generation cross Hereford-Black Angus (black baldy) steers. These steers were purchased in the spring and were sold in late September after removal from the second pasture. The initial weights for the steers ranged from 170 to 256 kilograms. The project design calls for the same breed of cattle to be used in subsequent years. Stocking rates may vary depending on the results of the earlier years of the study and current year plant production.

Grazing Schedule. The study design calls for livestock to be placed in one of the pastures on or about May 15th. Grazing in this pasture will continue until approximately July 15th or until a level of approximately fifty percent (50%) utilization of the forage has occurred. If 50 percent utilization has not been attained by July 15th, the cattle will still be moved to the other pasture on July 15th, where they will remain until approximately October 1st. After the first of October, the cattle will be removed from the second pasture and will be sold. The sequence of early and late season use will be alternated between the two pastures among successive years of grazing. This schedule will be followed for the first three years of the study. Depending on the results of the study, it is possible that both pastures will be rested the fourth year.

During the first year of the study (1988 growing season), the cattle were placed in the west pasture (34 hectares in size) on May 17th and were kept there until July 25th (69 days). On July 26th, they were released into the east pasture (40 hectares in size) and were allowed to graze until September 26th (62 days). It should be noted that the recorded annual precipitation for the first year of the study (1988) was 13.6 centimeters, only 41 percent of normal.

Dietary Supplements. No dietary supplements other than salt blocks will be provided. Salt blocks were strategically placed to enhance livestock utilization of all portions of the pasture.

Livestock Treatments. During the first year of the study, the cattle were inoculated with Ivomec, a parasiticide for the control of internal and external parasites of cattle, prior to being turned into the first pasture. The cattle were also ear-tagged with a fly tag in one ear and a numbered tag in the other, and were branded with the official Company insignia. To help control flies, a commercial oiler was placed in one pasture and a homemade backrubber was placed in the other. The cattle were also sprayed when they were moved from one pasture to the other. Permectrin II/10% EC was the chemical used on all three treatments mixed with the appropriate solution.

Measurements

Vegetation

The vegetation data collection program consists of obtaining information about productivity, forage utilization, species composition, shrub density, and vegetation canopy cover in each of the pastures.

Production/Utilization Data. Plant biomass data were collected using a harvest method and were measured using three separate, but complementary approaches. The first consisted of collecting biomass data at each of four 0.2 hectare exclosures located within the two pastures (Figure 1). Eight 1.0 square meter quadrats were clipped within each of the fenced exclosures. Data from these plots will provide information regarding long-term vegetation development in the absence of grazing. Associated with each of these control plots is a set of eight range production cages located near the control plots but not immediately adjacent to the fences (Figure 1). The data from these cages represent annual growth from sites that have been protected from grazing only during the current growing season. Comparison of data from these cages with the data from inside the control plots will provide the means for evaluating the long-term effects of grazing and grazing exclusion.

An additional 20 range utilization cages were located in each of the two pastures (Figure 1). The purpose of these cages was to obtain data on annual production throughout the pasture, and also to determine forage utilization at each of these sites. Biomass data were obtained by clipping the vegetation within a one-square meter quadrat inside the cages, and forage utilization was estimated by comparing biomass inside the cages with that from clipped 1.0 square meter quadrats located in the immediate vicinity outside of the cages. These sampling locations were scattered throughout the pasture so that all parts of the pastures were included in the sample. Some restrictions were placed on cage locations. Three of the cages were located in the vicinity of each of the control plots, thereby allowing evaluation of utilization in the areas close to the control plots. An additional three cages were located in the ephemeral drainages that occur in each of the pastures. This made it possible to examine whether the cattle tend to utilize the vegetation in the drainages to a greater extent than that on the uplands. The remaining eleven cages in each pasture were scattered so that all of the upland portions were represented in the sample. Biomass data were summarized by computing total biomass as well as the percent of biomass provided by each species.

Species Composition Data. Species composition data were collected in conjunction with biomass data. As each plot was clipped, the vegetation was sorted on the basis of species. Clipped samples were oven dried at 100° C for 24 hours and weighed to the

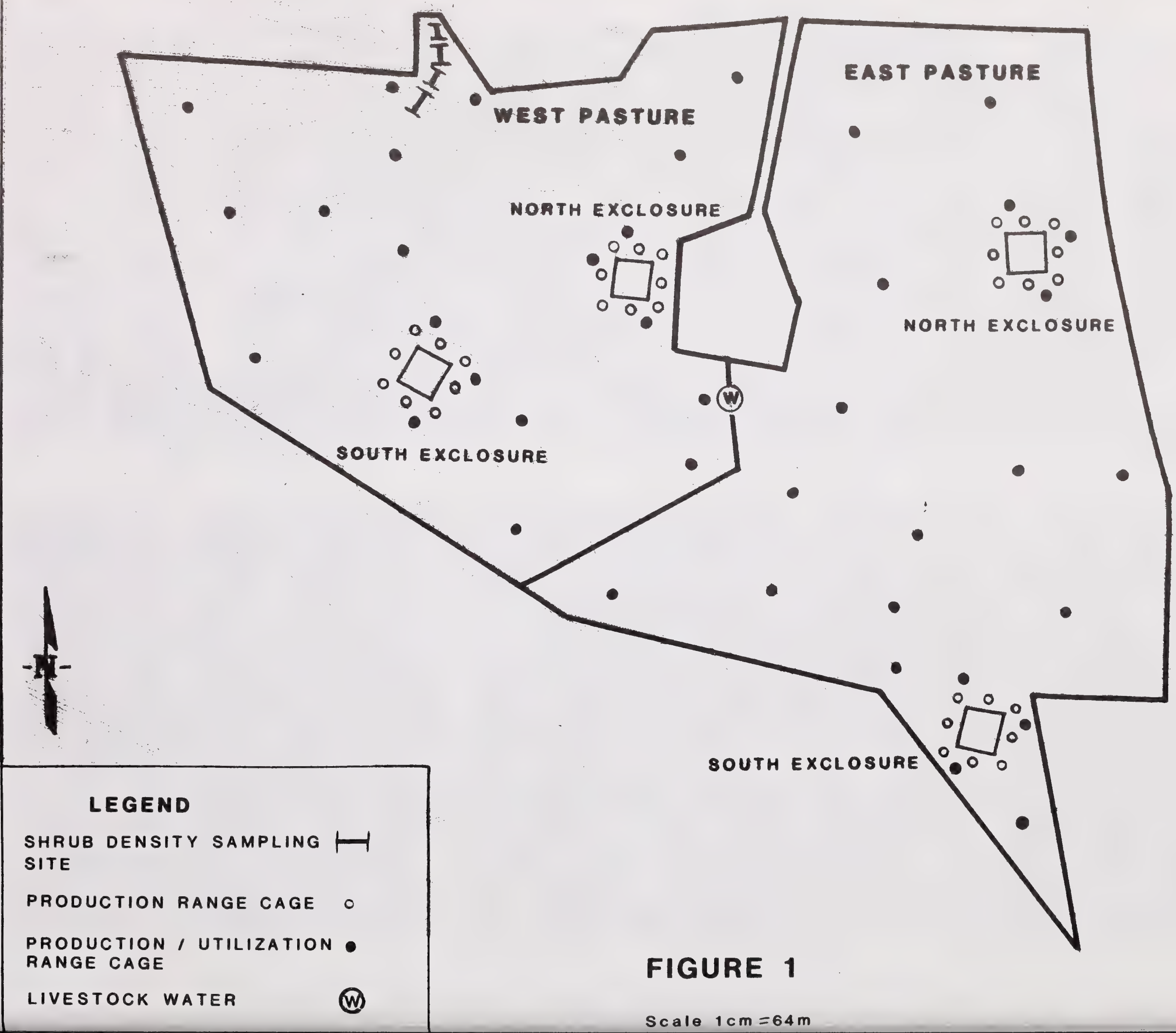

FIGURE 1

Scale 1cm = 64m

nearest 0.01 gm. Species were then evaluated on the basis of both percentage of total biomass (composition) and the number of species per square meter (richness).

Shrub Density Data. Shrub density was determined using a line strip transect. All of the shrubs occurring within one meter on either side of a 25 meter transect were counted and measured for height. Shrub density data were collected at each of the pasture-wide range cage production/ utilization plots and at several other selected sites where numerous shrubs had become established (Figure 1). By sampling these sites over time, it will be possible to evaluate grazing impacts on shrub density. All transects were permanently marked with steel fence posts and concrete reinforcing rods. Sampling permanently marked transects over time will improve the quality of the data for detecting increasing or decreasing trends in shrub density.

Cover Data. Prior to clipping, estimates were made of total vegetation canopy cover, cover by bare soil and cover by litter in each of the production and utilization quadrats. Cover data were summarized by computing mean values for each of the above parameters.

Sampling Schedule. The vegetation sampling schedule focused on two critical dates. The first was at the time when the livestock were moved from one pasture to another in July, and the second was in early October after the cattle were removed from the second pasture. In July, all of the large exclosures and their associated range cages were sampled. Additionally, all of the range cages and utilization plots in the pasture where the livestock had been removed were also sampled. In October, all of the range cages and utilization plots in the second pasture were sampled.

Livestock Performance.

Livestock performance was measured by the weight gain of the cattle. Each of the steers was individually weighed after being deprived of water and feed for eighteen (18) hours before release into the first pasture (May 17th). After completion of early season grazing (July 25th), the steers were trailed to a neighboring ranch where they were again deprived of water and feed for eighteen (18) hours and individually weighed on July 26th before being transferred to the second pasture. Final weights were obtained when the steers were removed from the second pasture on September 26th and weighed on September 27th, using the same methods. These data were used to determine total weight gains in each pasture and mean daily weight gains for each grazing period.

First Year Results and Discussion

Vegetation Characteristics

Since 1988 was the first year of the study, much of the data presented in this section simply characterizes the vegetation at the beginning of the project. In later years, these data will be used to evaluate any changes and trends which may occur. These data also provide insight into the homogeneity of the individual pastures as well as the comparability of the two pastures.

West Pasture. Reclaimed areas in the west pasture were sampled in 1987, thus providing preliminary information about structure and composition of these areas prior to the initiation of the grazing study. Of the three different sampling approaches employed in 1988 (exclosures, range cages associated with the exclosures, and the pasture-wide range cages), the data from the pasture-wide range cages provide the most useful data for overall characterization of west pasture vegetation. Therefore, only pasture-wide range cage data are presented here. It should be noted, however, that exclosure data in most cases yielded similar results.

The major species in the west pasture included thickspike wheatgrass, western wheatgrass and crested wheatgrass. Total production for these three species in 1988 was 430 kilograms/hectare, which was 94 percent of the total biomass in the pasture (Table 1). The remaining 6 percent of the biomass was distributed among 10 other species. Native cool season perennial grasses accounted for 71 percent of the biomass, and introduced perennial grasses accounted for 29 percent of the biomass. Total vegetation canopy cover was 11.4 percent; cover by litter and rock was 79.0 percent; and cover by bare soil was 9.6 percent (Table 2). Species richness averaged 2.95 species per square meter.

After early season grazing, total biomass in the grazed areas adjacent to the pasture-wide range cages was 138 kilograms/hectare, with thickspike wheatgrass, western wheatgrass and crested wheatgrass again accounting for 94 percent of the total biomass (Table 1). Total vegetation canopy cover was reduced to 4.9 percent, while cover by litter and rock remained high at 85.9 percent and cover by bare soil remained low at 9.2 percent (Table 2). Species richness was 2.85 species per square meter. The difference in biomass within the range cages (458 kilograms/hectare) and from adjacent open areas (138 kilograms/hectare) was statistically significant, clearly demonstrating the influence of the livestock. These data indicate that forage utilization by livestock during May-July was 69.9 percent, considerably higher than the project design level of 50 percent utilization.

Shrubs were small and scattered in the west pasture. Mean shrub density at the pasture-wide range cages was 49 individuals per hectare. Most of the shrubs did not exceed 10 centimeters in height (Table 3).

The differences in biomass and cover between 1987 and 1988 were quite striking (Tables 1 and 2). The 1987 season was much more favorable relative to available moisture, resulting in 240% higher total production than in 1988 (Table 1). Vegetation cover values show comparable differences (Table 2).

East Pasture. Based on the biomass data from the pasture-wide range cages, the major species in the east pasture include western wheatgrass, thickspike wheatgrass and crested wheatgrass. Total biomass

Table 1. Above-Ground Plant Biomass Summary for East and West Pastures, 1987-1988. 1988 Values Derived From Pasture-Wide Range Cage Locations.

	1987		1988			
Species	Pre-Grazing		Non-Grazed (Range Cages)		Grazed (Open Areas)	
	East Pasture	West Pasture	East Pasture	West Pasture	East Pasture	West Pasture
COOL SEASON PERENNIAL GRASSES	- - - - - - - - - - - - - kilograms/hectare - - - - - - - - - - - -					
Agropyron dasystachyum	484	286	111	172	50	62
Agropyron smithii	571	430	126	139	43	45
Agropyron cristatum/desertorum	213	147	74	119	45	22
Agropyron trachycaulum	126	132	53	<1	13	1
Other Species	33	89	25	27	2	8
Sub-Total	1427	1084	389	457	153	138
WARM SEASON PERENNIAL GRASSES	0	2	0	0	0	0
ANNUAL GRASSES	7	34	1	<1	<1	<1
PERENNIAL FORBS	0	0	0	0	0	0
ANNUAL/BIENNIAL FORBS	13	<1	0	<1	0	0
TOTAL HERBACEOUS SPECIES BIOMASS	1447	1120	390	458	153	138

Table 2. Cover Summary for East and West Pastures, 1987-1988. Values in Percent.

	1987		1988			
Species	Pre-Grazing		Non-Grazed (Range Cages)		Grazed (Open Areas)	
	East Pasture	West Pasture	East Pasture	West Pasture	East Pasture	West Pasture
	- - - - - - - - - - - - - - - % - - - - - - - - - - - - - - -					
TOTAL VEGETATION COVER	23	22	9	11	4	5
LITTER AND ROCK	61	64	83	79	86	86
BARE SOIL	16	14	8	10	10	9
TOTAL COVER	84	86	92	90	90	91

Table 3. **Shrub, Semi-Shrub and Cactus Density (number per hectare) and Height (cm) Summary for East and West Pastures, 1987-1988.**

Species	1987 Pre-Grazing		1988 First Year Grazing (Range Cage Sites)	
	East Pasture	West Pasture	East Pasture	West Pasture
Artemisia cana	17* (13)**	5 (9)		
Artemisia tridentata	12 (14)	114 (12)	20 (10)	
Atriplex canescens	230 (35)	5 (40)	170 (32)	10 (10)
Atriplex gardneri		10 (11)		
Ceratoides lanata	5 (40)	245 (17)		40 (10)
Gutierrezia sarothrae		10 (10)		
Opuntia polyacantha	35 (8)		40 (7)	
Total	299	369	250	50

* Density Values
** Height Values

Table 4. **Percent utilization among different species and in different topographic settings in the East and West Pastures.**

	East Pasture	West Pasture
Species		
COOL SEASON PERENNIAL GRASSES	------ % Utilization ------	
Agropyron dasystachyum	55	64
Agropyron cristatum/desertorum	39	82
Agropyron smithii	65	68
Agropyron trachycaulum	75	-
Other species	91	72
TOTAL BIOMASS	60	70
Topographic Setting (Based on Total Biomass)		
Entire Pasture	60	70
Drainages	79	84
Uplands	56	64

production for these three species was 311 kilograms/hectare, which was 80 percent of total production by all species (Table 1). These are the same three species that occurred as dominants in the west pasture. Slender wheatgrass was more prevalent in the east pasture, however, accounting for approximately 14 percent of the total biomass. While slender wheatgrass had the fourth highest production value, it was mostly restricted to ephemeral drainage sites.

Total biomass in the grazed areas adjacent to the pasture-wide range cages averaged 155 kilograms/hectare compared to 399 kilograms/hectare within the cages. This difference was statistically significant, and was a measure of forage utilization by livestock during the late season grazing period. Overall utilization in the east pasture was 61.4 percent, which was less than the utilization in the west pasture but still more than the targeted level of 50 percent. The major species in the open areas were the same as those encountered in the range cages (Table 1).

Species richness values for the sampling sites in the east pasture were comparable to those measured in the west pasture averaging 3.25 species per square meter at the pasture-wide range cage sites.

Total vegetation cover within the pasture-wide range cages was 8.6 percent; cover by litter and rock was 82.8 percent; and cover by bare soil was 8.6 percent (Table 2).

Shrub density in the east pasture was somewhat higher than that measured in the west pasture, although still relatively low. Total density (including semi-shrubs and cacti) was 249 individuals per hectare (Table 3). The shrubs in the east pasture tended to be taller than those in the west pasture. Mean height values for most species were more than 10 centimeters, with fourwing saltbush being the tallest (24-43 centimeters; Table 3).

Over the past two growing seasons, total production in the east pasture has varied in much the same manner as in the west pasture. In 1988, total production values were less than one-third of the value recorded for 1987. Total vegetation cover values reflected similar yearly variations (Table 2).

Forage Utilization. As mentioned above, overall utilization in the two pastures was 60 percent in the east pasture and 70 percent in the west pasture. Both of these values were higher than the target of 50 percent. At the beginning of the study, there was a considerable amount of standing dead plant litter in the pastures. It was decided to allow the livestock to remain in the pastures somewhat longer than originally planned to reduce the amount of the standing dead biomass.

Utilization of thickspike and western wheatgrasses was approximately the same in the two pastures. However, utilization of crested wheatgrass was approximately two times greater in the west pasture (Table 4). This difference may have been due to the fact that the west pasture was grazed early in the season, when palatability of the early-maturing crested wheatgrass was highest.

The estimates of overall utilization may be somewhat misleading since the degree of utilization was not consistent throughout the pastures (Table 4). Utilization of the vegetation in the ephemeral drainages was about 14 to 19 percent higher than on the uplands.

Livestock Responses.

Weight gain responses for the yearling steers are presented in Table 5. Total weight gain for the entire length of the grazing period was 108 kilograms per steer, which is equivalent to 0.83 kilograms per day. When evaluated with a t-test, livestock daily gains were found to be significantly greater during the first grazing period (1.03 +/- 0.11 kilograms/day) than they were during the second [0.60 +/- 0.12 kilograms/day (+/- values equal the standard deviation)]. This weight gain difference probably relates to factors other than vegetational differences between the two pastures, since the two pastures proved quite floristically similar. Lower gains later in the seson are characteristic as rangeland vegetation declines in forage quality following maturity, coupled with lower inherent growth rates of yearling livestock.

Preliminary Conclusions and Future Activities

From the standpoint of cattle performance, the first year of this grazing study must be considered a success. Season-long steer gains were judged excellent, comparing very favorably with gains reported in preceding grazing trials on both mined lands (e.g., DePuit and Coenenberg 1989, Hofmann and Ries (1988) and non-mined rangelands (e.g., Smoliak 1960, Hart et al. 1983) in the region. The fact that such gains were achieved in an abnormally dry year and under somewhat heavier grazing intensity than originally planned casts an even more favorable light on the capability of mined land vegetation to support season-long, rotational grazing. Results from succeeding years will indicate whether such forage value can be maintained after repeated animal use.

Conclusions on the influence of grazing on vegetation must necessarily be deferred, since first year sampling largely established only vegetation baselines from which to make future comparisons. Forage utilization (60-70 percent) in 1988 was higher than originally planned, but still was not considered excessive and did help to achieve a concurrent goal of plant litter reduction. Whether this and subsequent, more moderate levels of forage use in 1989 and 1990 have positive, neutral or negative impact on vegetation productivity or composition should become clear based upon future, post-grazing sampling. In short, the vegetation data base developed in 1987-1988 will be used in concert with future data to determine any changes in herbaceous species productivity/composition and shrub density attributable to grazing, thereby allowing an evaluation of the capability of vegetation to withstand the given rotational grazing regime.

Table. 5 Livestock Weight Responses During Early and Late Season Grazing, and Over Entire Grazing Period, 1988

Grazing Period/Dates-Durations	Beginning Weight	Ending Weight	Total Gain/ Animal	Average Gain/ Animal/Day
I. Early Season Grazing (5/17-7/25, 69 Days)	231 kg (510 lb)	302 kg (666 lb)	71 kg (156 lb)	1.03 kg (2.26 lb)
II. Late Season Grazing (7/26-9/26, 62 Days)	302 kg (666 lb)	339 kg (748 lb)	37 kg (82 lb)	.60 kg (1.33 lb)
III. Entire Grazing Season (5/17-7/25, 7/26-9/26, 131 Days)	231 kg (510 lb)	339 kg (748 lb)	108 kg (238 lb)	.83 kg (1.82 lb)

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COMPLEMENTARY GRAZING OF RECLAIMED MINED LAND AND NATIVE RANGELAND PASTURES IN MONTANA[1]

by

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and
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Abstract. A three year grazing study was conducted on Montana coal-mined lands revegetated with introduced, cool-season grasses and legumes. Objectives were to determine responses of mined land vegetation and soils to livestock (cattle) grazing, and to evaluate the capability of mined land vegetation to support livestock under two rotational grazing systems: exclusive grazing of mined land pastures season-long, and complementary mined land-native rangeland grazing. Spring and late summer grazing improved productivity of mined land vegetation, induced certain changes in plant species composition and diversity, and positively influenced certain soil attributes. Forage quality and animal gain data demonstrated highest utility of the introduced plant species for spring grazing, and lower value during the summer when animal performance on native range pastures was superior to that on mined land pastures. Total spring through summer cattle gains were higher with the complementary mined land-native rangeland grazing system than with the exclusive mined land system, although exclusive grazing of mined land vegetation produced acceptable season-long cattle gains.

Additional Key Words: Revegetation, Plant response, Forage Value

Introduction

Much of the land impacted by coal surface mining in the Northern Great Plains of the United States will be reclaimed to rangeland capable of supporting multiple uses. Since livestock grazing comprises the major agricultural use of rangelands throughout the region, successful reclamation must include establishment of vegetation which both can meet livestock forage requirements and persist under grazing pressure (DePuit

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1988). In a recent review of mined land grazing, Laycock (1989) noted basic forage requirements to include adequate quantity and quality of vegetation for planned use, no unacceptable forage elemental toxicity, and vegetation self-sustenance under grazing.

Progress in revegetation technology has largely laid to rest the question of re-establishing adequate forage quantity on northern plains mined lands (Ries and DePuit 1983, DePuit 1988), and documentation is beginning to accumulate that mined land vegetation can withstand grazing pressure if successfully established and grazed properly (e.g., Kleinman et al. 1984, Hofmann and Ries 1988, Laycock and McGinnies 1985, Schuman et al. 1986). Evidence also exists that grazing can be used on mined lands to change plant species composition or increase vegetation diversity (Kleinman et al. 1984, Young and Rennick 1983, Williamson 1981). Schuman et al. (1980) reviewed existing information on forage nutritional quality and trace element content on northern plains mined lands, and found little evidence for widespread elemental toxicity, although occasional nutritional imbalances and deficiencies were noted.

Another important aspect of mined land grazing involves its influence on minesoils and surface hydrology. Mined land research in North Dakota has noted increased runoff, reduced infiltration and increased compaction under overly heavy grazing intensities (Hofmann and Ries 1988, Hofmann et al. 1983). Conspicuously little information has been published, however, on grazing's effects on other physiochemical attributes of minesoils.

A key element in successful revegetation for grazing involves selection and establishment of plant species appropriate for the type of grazing operation planned for the site. Berg (1975) recognized at least three types of grazing land-use alternatives for mined lands: 1) special use areas for wildlife, emphasizing suitable browse species, 2) pastures for more general livestock [and wildlife] use, primarily composed of native species, and 3) special use pastures for livestock, composed of a limited number of highly productive, probably introduced plant species under more intensive management. In a later paper, Currie (1981) strongly supported the third of the above alternatives, citing the potential benefits of introduced (i.e., non-native) species on mined lands for increasing area-wide animal production when grazed complementarily with native pastures. Such "complementary" grazing systems basically involve rotational grazing on pastures with different species composition through a growing season, and have sometimes been noted to increase livestock production/carrying capacity and/or improve vegetation condition in the northern plains (e.g., Lodge 1970, Houston and Urick 1972, Smoliak 1968, Hart et al. 1983).

Objectives

A three year grazing study was implemented on coal-mined lands in southeastern Montana revegetated to a mixture of introduced plant species. This research was directed to meet two broad goals:

First, to determine the capability of the reclaimed site to withstand a specific regime of repeated spring and late summer grazing within a complementary grazing system. Specific objectives were to evaluate effects of the grazing regime on:

1) Productivity and composition of mined land vegetation,

and 2) Selected minesoil properties.

Second, to evaluate the utility of the given mixture of mined land plant species for support of cattle under complementary versus season-long rotational grazing. Specific objectives involved:

1) Characterization of forage nutritional quality of mined land vegetation during three portions of the grazing season,

and 2) Determination of animal performance under two rotational grazing systems.

Methods and Procedures

Study Area

The study was conducted at the Western Energy Company Rosebud Mine near Colstrip, southeastern Montana. Elevation of the site is 980m, and climate is semiarid and continental. Average annual precipitation is 40.1 cm, about one-half of which occurs as rain from April through July. Precipitation during the years of this study was near average in 1976 and 1977 (41 and 39 cm, respectively) and above average in 1978 (58 cm).

The area lies within the eastern Montana ponderosa pine savannah vegetation type (Munshower et al. 1978). Mixed prairie vegetation predominates, and cool-season perennial grasses are usually dominant on good condition range sites with forbs, warm-season grasses and shrubs in subdominant concentrations. Livestock (cattle) grazing constitutes the prime agricultural land use of much of the vicinity, and carrying capacities vary from 1.0 to 2.4 ha/AUM.

Spoil grading was completed at the mined land study site in 1971, leaving a rolling terrain with slopes of 3:1 or less gradient. The site was not topsoiled following grading. Spoils were fine sandy loams with low organic matter and macronutrient concentrations (DePuit and Coenenberg 1980). In May of 1972, a mixture of native and introduced grasses, shrubs and legumes (DePuit and Coenenberg 1980) was broadcast seeded, and nitrogen and phosphorus fertilizer was applied in 1972 and 1974. Although nearly half of the seeding mix was composed of native species, vegetation was dominated by a productive mixture of introduced grasses and legumes by 1975. Major plant species were crested wheatgrass (Agropyron cristatum), smooth bromegrass (Bromus inermis), tall wheatgrass (Agropyron elongatum), Ladak alfalfa (Medicago sativa) and yellow sweetclover (Melilotus officinalis).

In 1976, a 33 ha portion of the revegetated minesite was fenced to construct 8 pastures. A 9th pasture was located on nearby native rangeland that had been deferred from grazing for 7-8 years. Mined land pastures averaged 8.2 ha in size, while the rangeland pasture covered 14.0 ha.

Soils in the rangeland pasture were classified as Borollic Camborthids, fine silty, mixed (Lonna loam soil type), and possessed low organic matter and moderate macronutrient concentrations. The site was rated in good range condition, with annual productivity averaging 1165 kg/ha and livestock carrying capacity of 1.0 ha/AUM (Munshower et al. 1978). Dominant plant species were needle-and-thread (Stipa comata) and western wheatgrass (Agropyron smithii), with green needlegrass (Stipa viridula) and prairie junegrass (Koeleria cristata) as subdominant species.

Study Design

Two grazing systems were implemented in similar fashion each year from 1976 to 1978 (three years). System 1 involved rotational grazing exclusively on mined land vegetation during spring, summer and late summer periods. System 2 was complementary grazing of mined land pastures in the spring, the native rangeland pasture during the summer, and mined land pastures again in late summer. The average durations of grazing periods were 47 days (April 30 - June 15) for spring, 76 days (June 16 - August 31) for summer, and 23 days (August 31 - September 23) for late summer.

Yearling steers were used as experimental animals. Stocking rates were adjusted each year based upon estimated forage availability and a desired moderate level of forage utilization (55-60 %) during each grazing period in each pasture. Stocking rates on mined land pastures averaged 2.5, 1.5 and 1.2 AUM/ha during spring, summer and late summer grazing periods, respectively, which were 1.5 to 6 times higher than rates typical on native rangeland of the area and similar to rates reported for introduced species pastures elsewhere in the region (e.g., Houston and Urick 1972).

Each of the 8 mined land pastures and the native rangeland pasture received the same grazing treatment three years in succession from 1976 to 1978. Experimental animals were introduced into mined land Pastures 1, 2 and 3 in spring. The herd was divided during the summer period to move cattle either into mined land Pastures 7 and 8 (System 1) or into the native range Pasture 9 (System 2). During late summer, the cattle were moved back into Pastures 1, 2 and 3, with the same individual animals assigned to the specific pastures they occupied the preceding spring.

Mined land Pastures 1 through 6 represented three replications of two treatments: spring/late-summer grazing (Pastures 1, 2 and 3), and no grazing (control)(Pastures 4, 5 and 6). Vegetation and soils data were compared between these two treatments before grazing and during each of the three grazing seasons to address our first goal of evaluating minesite capability to withstand spring/late-summer grazing. Plant responses were determined by measurements of forage utilization and peak aboveground biomass of dominant and subdominant species/growth forms; biomass data were also relativized to derive the Shannon-Wiener index of vegetation diversity (Chambers 1983). Soil attributes sampled included major nutrients, organic matter content and bulk density. Plant and soil sampling methods were described in detail by DePuit and Coenenberg (1980).

Our second goal of evaluating utility of mined land vegetation for grazing was addressed in two ways. First, seasonal differences in minesite forage quality were determined by nutritional analyses of plant tissue collected in the spring, summer and late summer grazing periods. Forage samples of all dominant plant species were analyzed for protein, total digestible nutrient and mineral content using procedures described by DePuit and Coenenberg (1980). A second approach, for evaluating the two grazing systems, involved comparing animal weight gains/losses between the complementary and season-long grazing schemes. Experimental animals were individually weighed before and after each seasonal grazing period in each year to provide an indication of animal performance over the grazing period.

Vegetation, animal and soils data were subjected to analyses of variance. Duncan's Multiple Range test was used to determine significant treatment differences, and $P < 0.10$ was used for all mean separations.

Results and Discussion

Site Responses to Spring/Late-Summer Grazing

Vegetation. DePuit and Coenenberg (1980) presented forage utilization data for the spring and late summer grazing periods. Total forage consumption was moderate, averaging 60% during the spring and 48% during the late summer.

During the spring, cattle utilized crested wheatgrass, smooth bromegrass and legumes at similarly high percentages (53-64%), while utilization of tall wheatgrass and other perennial grasses was far lower (25-33%). Grazing preference changed somewhat during the late summer, with heaviest utilization of smooth bromegrass (66%) and alfalfa (51%), and much lower consumption (27-38%) of all other species.

Plant productivity responses to grazing pressure are provided in Table 1. Total vegetation biomass was statistically similar between grazed and ungrazed pastures in 1975 and increased from 1975 to 1978 within both sets of pastures; by 1978, however, total productivity became significantly greater in grazed than in ungrazed pastures. These total productivity relationships can be largely tied to legume responses, since combined legume species biomass exhibited response patterns identical to those of total biomass.

Table 1 indicates higher total perennial grass biomass in grazed than ungrazed pastures both before grazing in 1975 and after grazing in 1978, and no significant change over time within either set of pastures. Individual grass species, however, did not always respond similarly. Productivity of crested wheatgrass and combined subdominant (i.e., "other") perennial grasses was relatively little-influenced by grazing, since biomass was higher in grazed than ungrazed pastures in both 1975 and 1978. Tall wheatgrass and smooth bromegrass biomass means were similar between grazed and ungrazed treatments in 1975. By 1978, tall wheatgrass productivity had declined significantly in ungrazed pastures while remaining constant under grazing, suggesting that three years of grazing had benefited this species. In contrast, smooth bromegrass biomass was significantly lower in grazed than in ungrazed pastures in 1978, despite an increase from 1975 to 1978 under both treatments. Successive spring/late-summer grazing thus retarded the expansion of smooth bromegrass.

Table 1. Comparison of estimated aboveground biomass production (kg/ha) in spring/late summer grazed and ungrazed mined land pastures prior to grazing initiation (1975) and after three years of grazing (1978).[1]

Plant Species/Class	Year/Grazing Treatment			
	1975 (Pre-Grazing)		1978 (Post-Grazing)	
	Grazed[2]	Ungrazed[3]	Grazed[2]	Ungrazed[3]
	kg/ha			
PERENNIAL GRASSES:				
Agropyron cristatum	1270 a	970 b	902 b	684 c
Agropyron elongatum	272 a	192 a	220 a	26 b
Bromus inermis	325 c	272 c	576 b	674 a
Other perennial grasses	102 a	46 b	82 a	48 b
Total perennial grasses	1969 a	1480 b	1780 a	1432 b
LEGUMES:				
Medicago sativa	475[4]	477[4]	1623 a	1424 a
Melilotus officinalis			2 a	1 a
Other legumes	25 b	15 b	106 a	40 b
Total legumes	500 c	492 c	1731 a	1465 b
OTHER SPECIES:				
Annual grasses	20 b	29 b	57 a	1 c
Annual & perennial forbs	0 a	0 a	4 a	6 a
Shrubs & half-shrubs	1 a	7 a	1 a	7 a
TOTAL LIVE VEGETATION:	2490 cd	2008 d	3573 a	2911 bc

[1] Within a plant species/class row, year-grazing treatment means followed by same letter are not significantly different at $P < 0.10$

[2] Means of Pastures 1, 2 and 3

[3] Means of Pastures 4, 5 and 6

[4] M. sativa and M. officinalis not differentiated in 1975

Biomass composition data for individual dominant species and groups of subdominant species were used to construct Shannon-Wiener indices (H′) of vegetation diversity. Differences in H′ values can be attributed entirely to differences in the evenness component of the index, since the richness component was identical for all treatment/year combinations. H′ values were quite similar between grazed (0.58) and ungrazed (0.59) pastures prior to grazing in 1975. However, H′ increased from 1975 to 1978 in grazed pastures while declining in ungrazed pastures. This resulted in a considerably higher diversity index value in grazed (0.63) than in ungrazed (0.51) pastures after completion of the three year grazing term.

The H′ relationships suggest that grazing enhanced diversity of mined land vegetation through higher equity of composition among dominant species and groups of subdominant species.

However, from a floristic richness standpoint grazed pastures possessed only slightly higher numbers of plant species than ungrazed pastures in 1978 (DePuit and Coenenberg 1980); grazing thus did not appear to influence species richness of pastures as much as equity of species distribution.

Plant frequency data for individual species (DePuit and Coenenberg 1980) further elucidated effects of grazing on pasture floristics. Few differences in species frequency existed between grazed and ungrazed pastures prior to grazing in 1975. After three years of grazing, no species exhibited statistically higher frequency in ungrazed than in grazed pastures, while several dominant and subdominant species occurred with significantly greater frequency in grazed pastures. Summed frequency of rare (< 5% individual species frequencies) perennial grasses, legumes, forbs and shrubs in grazed pastures (19%) was over twice that in ungrazed pastures (9%) in 1978. These relationships indicate that three years of spring/late summer grazing never reduced and often increased distribution of specific dominant, subdominant and rare plant species.

Prior to grazing initiation in 1975, both spring/late summer grazed and ungrazed mined land pastures were characterized by massive accumulations of undecomposed standing and ground plant litter -- a consequence of high plant productivity under fertilization in preceding years. Table 2 presents plant litter accumulation responses under grazed and ungrazed treatments through the three year grazing term. With no grazing, standing dead litter accumulation was still relatively high in 1976, declined in 1977, and remained constant in 1978; ground litter in these pastures remained similarly high from 1976 to 1977, and declined in 1978. Despite these staggered but nonetheless eventual standing dead and ground litter declines, litter accumulations in ungrazed pastures were still substantial in 1978, and in all years were significantly higher than those in grazed pastures. Standing dead litter became greatly reduced in grazed pastures after only one year of grazing in 1976, and eventually declined further in 1978. Ground litter was also significantly reduced after the first year of grazing, and became progressively lower after the second and third years of grazing.

Table 2. Effects of spring/late summer grazing and non-grazing on accumulations of standing dead and ground plant litter in mined land pastures after the first (1976), second (1977) and third (1978) years of grazing.[1]

Plant Litter Class/Year	Grazing Treatment	
	Grazed[2]	Ungrazed[3]
	-------- kg/ha	------
STANDING DEAD LITTER:		
1976 (after 1 year grazing)	115 c	1185 a
1977 (after 2 years grazing)	117 c	584 b
1978 (after 3 years grazing)	47 d	421 b
GROUND LITTER:		
1976 (after 1 year grazing)	1379 c	2964 a
1977 (after 2 years grazing)	754 d	2774 a
1978 (after 3 years grazing)	550 e	1960 b

[1] Within litter classes, year-grazing treatment means followed by same letter are not significantly different at $P < 0.10$

[2] Means of Pastures 1, 2 and 3

[3] Means of Pastures 4, 5 and 6

Soils. Soil testing after the first, second and third years of grazing yielded only small differences in soil phosphorus and potassium content between non-grazed and grazed mined land pastures (DePuit and Coenenberg 1980), indicating little influence of grazing on these soil nutrients. Grazing did affect soil nitrogen and carbon regimes, however. Table 3 indicates no statistically significant differences in organic carbon content in the upper 15 cm of minesoils between non-grazed and grazed pastures after three years of grazing, despite slightly higher carbon content in grazed pastures. However, total nitrogen (N) content was significantly higher in grazed than in non-grazed pasture soils in 1978, causing a significantly lower soil carbon: nitrogen (C:N) ratio in grazed than in non-grazed pastures by the end of the third, final grazing season. It is also noteworthy that the C:N ratio in grazed pastures in 1978 was substantially lower than the ratio prior to grazing initiation early in 1976.

Grazing thus promoted a reduction of the elevated C:N ratios that are often characteristic of surface minesoils in years following initial establishment of highly productive vegetation, primarily due to increased total soil N. This may have been caused by increased soil incorporation of green, lower C:N ratio live plant biomass through livestock trampling. Such increased plant biomass incorporation may also have contributed to the slightly but significantly higher soil cation exchange capacities in grazed pastures in 1978 (Table 3). However, most of the added N was apparently bound in non-plant available organic form, since concentrations of available inorganic (NO_3 + NH_4) N were still low in 1978 and not different between grazed and non-grazed pastures.

Soil bulk density data were collected to determine whether repeated spring/late summer livestock use would induce higher soil compaction in mined land pastures. Table 3 indicates no difference in bulk density between non-grazed pastures and general use areas within grazed pastures either before (1975) or after two years of grazing (late 1977), and bulk density did not change significantly from 1975 to 1977 within either grazing treatment. However, bulk density did increase significantly from 1975 to 1977 within heavy livestock use areas of grazed pastures (e.g., along fencelines and near water sources), to become significantly higher at 1.58 g/cm^3 than that in non-grazed pastures in 1977. These findings suggest that the moderate intensity of livestock use in grazed pastures had no major influence on pasture-wide soil bulk density, in agreement with results of mined land research in North Dakota (Ries and Hofmann 1984, Hofmann and Ries 1988) which found negative effects of grazing on surface hydrologic attributes of minesoils only under heavier grazing intensities. In our study, only localized areas of livestock concentration experienced elevated bulk densities -- presumably caused by increased soil compaction from animal trampling.

Table 3. Responses of selected attributes of the upper 15 cm of soils in non-grazed and spring/late summer grazed mined land pastures prior to grazing and after 2 to 3 years of grazing.[1]

Soil Attribute/Sampling Date	Mined Land Pastures Ungrazed[2]	Mined Land Pastures Grazed[3]
TOTAL NITROGEN (%):		
1976 (Pre-grazing)[4]	------- 0.086 -------	
Late 1978 (after 3 years grazing)	0.040 b	0.062 a
CARBON (%):		
1976 (Pre-grazing)[4]	-------- 1.76 -------	
Late 1978 (after 3 years grazing)	0.70 a	0.90 a
CARBON/NITROGEN RATIO:		
1976 (Pre-grazing)[4]	-------- 20.5 -------	
Late 1978 (after 3 years grazing)	17.5 a	14.5 b
AVAILABLE (NH_4 + NO_3) NITROGEN (ppm):		
1976 (Pre-grazing)	--------- 5 ---------	
Late 1978 (after 3 years grazing)	3 a	4 a
CATION EXCHANGE CAPACITY (meq/100g):		
1976 (Pre-grazing)	-------- nd[5] -------	
Late 1978 (after 3 years grazing)	4.1 b	6.0 a
BULK DENSITY (g/cm^3):		
1975 (Pre-grazing)	1.30 a	1.27 a
Late 1977 (after 2 years grazing)	1.35 a	1.45 a[6]

[1] Within attributes and sampling dates, pasture means with same letter are not significantly different at $P < 0.10$

[2] Means among Pastures 4, 5 and 6

[3] Means among Pastures 1, 2 and 3

[4] From a similar, immediately adjacent minesite

[5] nd - not determined

[6] Within areas of general, non-concentrated livestock use

Grazing Utility of Vegetation

Forage Quality. Nutritional quality data collected during the first and second years of study provided one indication of the relative suitability of mined land vegetation for grazing during the spring, summer and late summer periods utilized in the rotational grazing program. Table 4 indicates maximum overall forage quality for most species in the spring, due to usually highest concentrations of protein, total digestible nutrients (TDN), phosphorus (P), copper (Cu), sulfur (S) and zinc (Zn). With few exceptions, these forage quality attributes were similarly reduced in the summer and late summer. However, concentrations of certain other mineral nutrients were highest in some plant species during the late summer, including calcium in most grasses and all legumes, iron in both grasses and legumes, and manganese in grasses.

Concentrations of the potentially harmful trace elements fluorine, cadmium, lead, nickel and selenium were low (DePuit and Coenenberg 1980), and did not differ significantly among seasons for either grasses or legumes. However, seasonal differences in molybdenum (Mo) content were apparent for certain species (Table 4). Mo content of smooth bromegrass tended to increase from spring to summer to late summer. Although Mo content of alfalfa declined from spring to summer/late summer, both it and yellow sweetclover possessed much higher Mo concentrations than grasses throughout the season. These relationships, in concert with Cu responses, caused Cu:Mo ratios to decline from spring through late summer for smooth bromegrass and, less markedly, crested wheatgrass; Cu:Mo ratios were consistently low for both alfalfa and sweetclover season-long.

The observed seasonal decline in overall forage quality was not considered unusual in light of similar temporal changes in forages grown on non-mined lands of the area (e.g., Munshower and Neuman 1978, Houston and Urick 1972). Munshower and Neuman (1980) found higher concentrations of several macronutrients in forages grown on topsoiled mined lands than those on non-topsoiled sites. It is therefore quite possible that plant forage quality in the present study would have been higher if the site had been topsoiled, as is currently practiced on mined lands of the area. For example, subsequent findings of Neuman and Munshower (1984) indicated that spoil coverage with topsoil

Table 4. Selected forage quality attributes of dominant plant species and classes in mined land pastures during spring, summer and late summer grazing seasons.[1]

		Grazing Season		
Attribute	Plant Species/Class[2]	Spring	Summer	Late Summer
PROTEIN (%)	*A. cristatum*	14 a	3 c	6 b
	A. elongatum	15 a	6 b	4 b
	B. inermis	15 a	8 b	8 b
	Legumes	27 a	11 b	12 b
TOTAL DIGESTIBLE NUTRIENTS (%)	*A. cristatum*	74 a	61 ab	51 b
	A. elongatum	66 a	66 a	46 b
	B. inermis	70 a	52 b	43 b
	Legumes	65 a	63 ab	52 b
CRUDE FIBER (%)	*A. cristatum*	25 b	38 a	37 a
	A. elongatum	29 b	40 a	39 a
	B. inermis	25 b	33 a	31 ab
	Legumes	19 b	30 a	35 a
PHOSPHORUS (%)	*A. cristatum*	0.18 a	0.06 b	0.12 ab
	A. elongatum	0.14 a	0.09 ab	0.06 b
	B. inermis	0.23 a	0.10 b	0.11 b
	M. sativa	0.22 a	0.08 b	0.12 b
	M. officinalis	nd[3]	0.10 a	0.10 a
CALCIUM (%)	*A. cristatum*	0.24 b	0.24 b	0.46 a
	A. elongatum	0.27 a	0.16 a	0.26 a
	B. inermis	0.25 b	0.38 ab	0.56 a
	M. sativa	1.18 b	1.04 b	1.48 a
	M. officinalis	nd	0.88 b	1.45 a
COPPER (ug/g)	*A. cristatum*	5.8 a	3.2 b	3.4 b
	A. elongatum	6.1 a	4.1 b	3.5 b
	B. inermis	6.7 a	4.3 b	4.3 b
	M. sativa	8.4 a	6.7 a	7.1 a
	M. officinalis	nd	6.0 a	5.0 a
MOLYBDENUM (ug/g)	*A. cristatum*	0.7 a	0.6 a	0.9 a
	A. elongatum	1.0 a	0.8 a	0.6 a
	B. inermis	0.8 b	1.0 ab	1.4 a
	M. sativa	3.0 a	2.0 b	2.2 b
	M. officinalis	nd	2.5 a	2.1 a
COPPER/MOLYBDENUM RATIO	*A. cristatum*	8.3 a	5.3 ab	3.8 b
	A. elongatum	6.1 a	5.1 a	5.8 a
	B. inermis	8.4 a	4.3 b	3.0 b
	M. sativa	2.8 a	3.4 a	3.2 a
	M. officinalis	nd	2.4 a	2.4 a
SULFUR (%)	Per. grasses	0.25 a	0.18 b	0.20 ab
	Legumes	0.30 a	0.25 b	0.27 ab
ZINC (ug/g)	Per. grasses	23 a	18 a	23 a
	Legumes	36 a	25 b	26 b
MANGANESE (ug/g)	Per. grasses	40 b	46 b	93 a
	Legumes	32 a	39 a	45 a
IRON (ug/g)	Per. grasses	176 b	163 b	509 a
	Legumes	115 b	201 ab	351 a

[1] Within species/classes and attributes, means followed by same letter are not significantly different at $P < 0.10$

[2] Plant class data for legumes are means between *M. sativa* and *M. officinalis*, and for perennial grasses are means among *A. cristatum*, *A. elongatum* and *B. inermis*; species differences within these classes were minor for associated attributes (DePuit and Coenenberg 1980)

[3] nd = not determined

effectively precluded depressed Cu:Mo ratios for most plant species -- including the Mo-accumulating legumes alfalfa and yellow sweetclover. With respect to copper, it should also be noted that limited availabilty in forage is commonplace in certain species and/or later in the growing season on non-mined rangeland as well as mined lands in the area (Munshower and Neuman 1978). Furthermore, Cu:Mo ratios and Mo content of forages in the present study were never expressed at critical levels (i.e., Cu:Mo < 2 and Mo > 5 ug/g) for any plant species in any season, and no copper deficiency symptoms were apparent in cattle even during the late summer grazing period. The latter fact supports the contention of Neuman and Munshower (1984) that when relatively limited copper availability does develop for certain species (i.e., legumes) in mixed stands on mined lands, it may be compensated by higher copper availability to livestock from other, concurrently grazed species.

Animal Performance. Figure 1 contrasts average daily weight changes for yearling steers under season-long rotational grazing exclusively on mined land pastures (System 1) versus complementary rotational grazing of mined land pastures in spring, native rangeland pastures in summer and mined land pastures again in late summer (System 2).

Figure 1(A) indicates no difference in animal performance between steers destined for the two grazing systems during the spring (May through mid-June) grazing period, suggesting no variation in condition/ inherent responsiveness between animal groups. Steer gains proved higher in spring than in all other grazing seasons. Steer gains declined from spring to summer under both grazing systems, but were most reduced for animals in mined land pastures in System 1; average daily gains proved significantly higher in native rangeland than in mined land pastures during the summer. Additional, interim cattle weight data collected within the summer grazing periods of 1977 and 1978 (DePuit and Coenenberg 1980) indicated the greatest depression of animal gain to have occurred during the latter part of the summer period (August) in mined land pastures. Steers performed the poorest in both systems on mined land pastures during the late summer grazing period; indeed, steers in System 2 actually lost weight after being rotated from rangeland back into mined land pastures.

Although possibly influenced by differences in animal condition through the season, the above relationships suggest forage value of mined land pasture vegetation to have been highest during spring followed by a progressive decline through late summer, in general agreement with plant nutritional quality data and results of many previous seasonal grazing trials on non-mined lands. It is noteworthy, however, that later (October) grazing in 1977 with a second group of experimental animals yielded much higher average daily gains (0.8 kg/animal/day, DePuit and Coenenberg 1980), suggesting enhanced forage value of mined land vegetation for later fall grazing following appreciable regrowth.

The higher steer gains in the native rangeland pasture during summer (Figure 1[A]) demonstrate the given mix of introduced plant species in mined land pastures to have been inferior to native species for mid-season grazing. Figure 1(B) accordingly indicates steer gains over the combined spring-summer periods to have been significantly higher under System 2 than under System 1, suggesting the superiority of the complementary mined land/rangeland system. However, system comparison over all three periods combined (i.e., spring through late summer, Figure 1[C]) yielded no significant difference in gains between Systems 1 and 2 -- largely because of the net loss in weight for System 2 steers when reintroduced to mined land pastures in

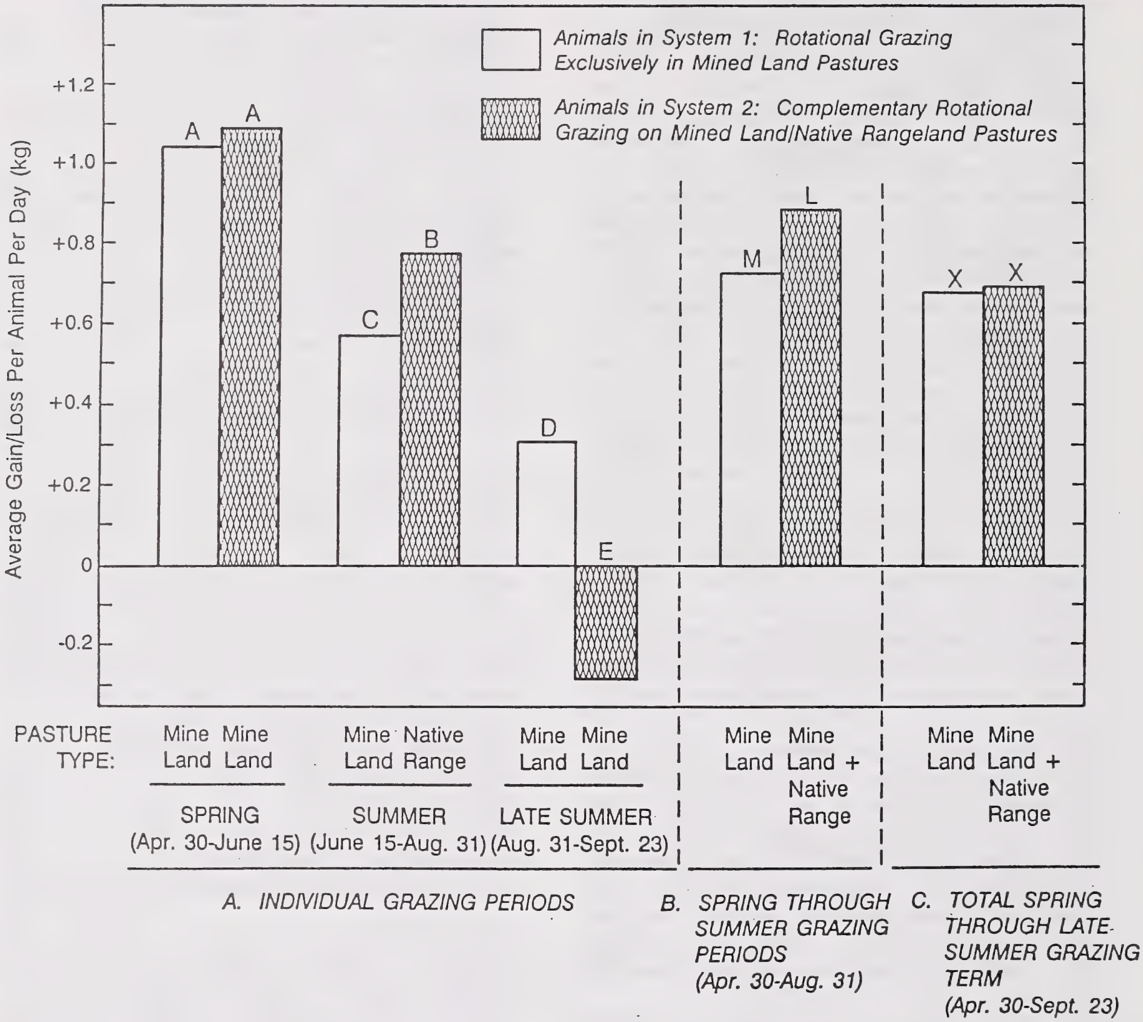

Figure 1. Average daily gain or loss of yearling steers under two grazing systems, A) in each grazing period, B) from spring through summer, and C) from spring through late summer; 1976-1978. Within A, B and C, bars with same letter are not significantly different at P < 0.10.

late summer. Therefore, while complementary grazing of introduced mined land plant species in spring and native rangeland species in summer may be recommended, late summer rotation back to mined land pastures would appear counterproductive.

Discussion

In summarizing his recent review of mined land grazing, Laycock (1989) concluded that livestock can be grazed successfully on reclaimed lands with no detrimental influence on vegetation or surface hydrology -- if proper grazing management is practiced. Our findings support this conclusion, since the given rotational system and moderate intensity of grazing in fact enhanced total vegetation productivity, appeared to increase structural diversity of the plant community and improve distribution of certain species, and had neutral to positive impacts on soils.

Hart and Norton (1988) noted that grazing may sometimes increase forage production directly through physiologic stimulation of additional plant growth, or indirectly through beneficial effects on nutrient cycling and/or growth environment characteristics. In terms of the latter, the reduction of massive plant litter accumulation in grazed mined land pastures may have been a major contributor to enhanced vegetation condition. Natural mulch can significantly influence the function of rangeland plant communities in complex and often varying ways (Tomanek 1969); excessive litter in ungrazed rangeland communities has sometimes been noted to depress productivity (and diversity) of vegetation (Weaver and Rowland 1952, and others). Increased soil incorporation of plant litter through livestock activity also may have accelerated carbon and nutrient cycling (e.g., the eventually lowered soil C:N ratios) and improved other soil characteristics (e.g., the increased soil cation exchange capacity), hence promoting soil development and, indirectly, plant growth. Thus, grazing may comprise a managerial approach to enhance pedogenesis on minespoils.

However, Hart and Norton (1988) also pointed out the difficulty of separating the effects of grazing on forage productivity from those on botannical composition. Indeed, changes in species composition occurred in response to grazing in the present study. These compositional changes were presumably related to differences in grazing pressure on and resultant reaction among species, which may in turn have altered interspecific competition regimes. For example, crested wheatgrass remained apparently unaffected by three consecutive years of grazing despite relatively high utilization during the spring, in accordance with its long-known capability to withstand grazing (Smoliak 1968, Houston and Urick 1972, Frischknecht and Harris 1968). Conversely, the less palatable and utilized tall wheatgrass was beneficially affected, while the more palatable and heavily utilized (in both spring and late summer) smooth bromegrass was detrimentally influenced by repeated spring/late summer grazing. These differing responses among species suggest a potential role of grazing for manipulating species composition on mined lands, as proposed by DePuit (1988) and sometimes demonstrated by others (e.g., Williamson 1981).

Forage nutritional quality and animal weight responses indicated highest grazing value of the given mix of introduced plant species in the spring and declining value later in the season, as expected based upon results of previous studies of non-mined land pastures with similar composition elsewhere in the northern great plains (Houston and Urick 1972, and others). Spring gains of steers on mined land pastures (1.06 kg/animal/day) were very similar to early-season gains of yearling cattle reported by a number of grazing studies of introduced species on non-mined lands (e.g., 0.91 to 1.16 kg/animal/day; Malechek 1986, Frischknecht and Harris 1968). The reduced forage quality of the introduced species following spring resulted in better animal performance on native vegetation during the summer, and an apparent superiority of the complementary mined land-rangeland grazing system from spring through summer (although not through late summer). Thus, the given mixture of introduced species would appear to have greatest utility for special-use, early season grazing rather than for season-long, general grazing. Such optimal use has been often suggested for crested wheatgrass, one of the dominant components of mined land pasture vegetation, whether on mined lands (DePuit 1986) or on non-mined rangeland (Malechek 1986).

It should be noted, however, that average steer daily gains over the entire season with exclusive grazing on mined land vegetation (0.68 kg/animal/day) were similar to or better than gains typical for season-long grazing of native rangeland in the region (Smoliak 1960, Hart et al. 1983). Furthermore, no symptoms of malnutrition were apparent in cattle in mined land pastures even in late summer when certain nutritional attributes (i.e., protein, phosphorus, copper) were lowest in certain plant species. These findings suggest that although - again - they may be optimally suited for use in the spring under complementary grazing, the given mix of mined land plant species nonetheless can adequately support cattle season-long. The latter conclusion is supported by initial findings of a seasonality of use study on North Dakota mined lands revegetated to introduced cool-season species (Ries and Hofmann 1984), in which no differences in season-long cattle gains were noted between mined land and adjacent native rangeland pastures.

Although late summer rotation of cattle back into mined land pastures was not beneficial, the improved animal performance in 1977 under later fall grazing suggests the given mixture of species might have value for rotational grazing during that period, at least in years with adequate fall regrowth of the cool-season species. In retrospect, the third period of the complementary grazing rotation was probably scheduled too early in 1976 and 1978 (i.e., late summer) to yield any chance of positive animal response.

Conclusions

Results of this study were positive in terms of our first broad goal of evaluating the capability of the reclaimed site to withstand repeated spring and late summer grazing. Grazing enhanced overall productivity and, to a lesser extent, diversity of vegetation. No negative effects of grazing were evident on soils, and grazing positively influenced plant litter dynamics and certain facets of soil development. Changes in plant species composition occurred in consequence of grazing, suggesting a role of grazing for manipulating the nature of vegetation on mined lands.

The second broad goal of research was to evaluate the suitability of the given mixture of introduced, early season phenology plant species on mined lands for supporting cattle under complementary versus season-long use. Results indicated greatest value for spring use within a complementary mined land-native rangeland grazing system, in general agreement with past research with such species on non-mined lands. However, the mined land vegetation did prove capable of adequately supporting cattle even when grazed exclusively throughout the spring-late summer rotation. Forage quality and animal performance, in most respects, compared very favorably with results of other research on non-mined lands. The fact that such positive results occurred on a non-topsoiled site suggests the potential for even better grazing value on mined lands topsoiled and reclaimed under present, more advanced technology.

Acknowledgments

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Water

Session Chairmen: R. Kleinmann and P.M. Erickson

RECLAMATION OF ABANDONED MANGANESE MINES IN SOUTHWEST VIRGINIA AND NORTHEAST TENNESSEE[1]

by
Jack A. Muncy[2]

ABSTRACT. In 1985 the Tennessee Valley Authority (TVA) initiated a plan to rehabilitate the South Fork of the Holston River Basin. The objective was to identify and seek resolution of all major water resource problems in the basin area through integrated management. A major component of the plan is alleviating nonpoint source water pollution impacts from abandoned manganese mine lands. Most of these abandoned mine lands (AML) were created in the years prior to State noncoal mineral mining and reclamation laws. TVA has taken a lead role in addressing this land and water quality problem. Cooperative project activities resulted in the reclamation of 72 separate minesites covering 521 acres in a four-county, two-state area.

Additional Key Words: erosion; sediment; land rehabilitation

Introduction

Manganese mining in southwest Virginia and northeast Tennessee began on a small scale during the World War I era (figure 1). The early mining was for the most part conducted underground by the pick and shovel method and disturbed limited acreage. In 1941, the U.S. Government started a program for stockpiling strategic metals such as manganese (Tipton 1988). The manganese was needed by the steel industry to make a high quality steel alloy for weaponry and planes. Also in 1941, methods were developed for making pure manganese from common manganese ore by using an electrolytic process. These new needs and processes stimulated manganese mining in southwest Virginia and northeast Tennessee. Surface mining with heavy equipment (i.e., small shovels and bulldozers) began in the early 1940s and fluctuated with market conditions until about 1958, when the U.S. Government's procurement program ended.

Surface mining was unregulated and created at least 130 separate minesites covering 747 acres in a four-county, two-state area (table 1). No reclamation or environmental protection standards were attempted on these mines because of the economic conditions during that period. The mining was also done several years before State laws came about to regulate the environmental impacts of noncoal mineral mining. Tennessee passed its law in 1968 and Virginia enacted its provisions in 1969. This paper summarizes reclamation efforts involved in this AML stabilization project.

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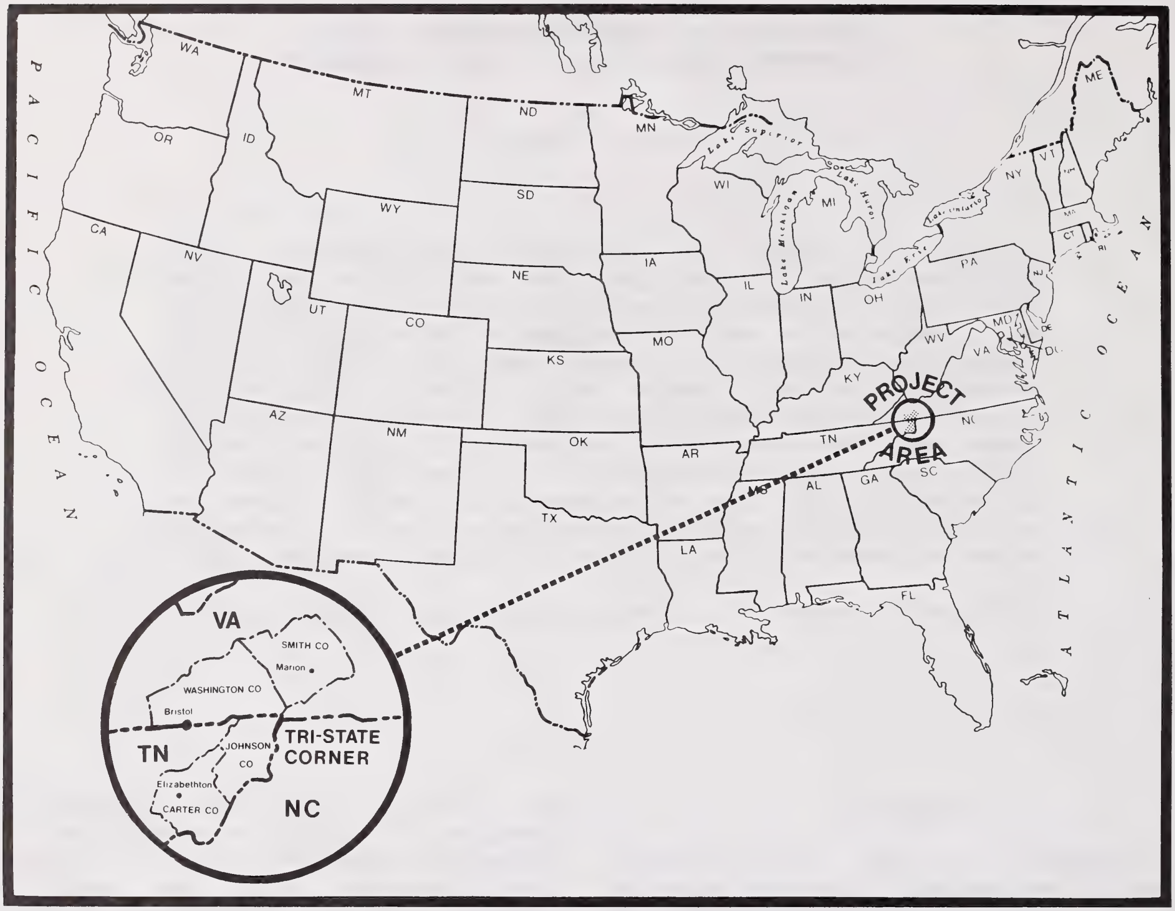


Figure 1. Location of Project Area.

Table 1. Status of abandoned manganese mines in the Tennessee Valley.

Mine Location	No. of Mines[1]	Disturbed	Naturally Revegetated	Reclaimed by TVA and Cooperators	Unreclaimed
		acres			
TN Counties					
Carter	15	79	11	68	–
Johnson	46	183	54	115	14
VA Counties					
Smyth	56	414	92	322	–
Washington	13	71	55	16	–
Total	130	747	212	521	14

[1] Also includes a limited number of abandoned sand mines and rock quarries.

In 1985 TVA took a lead role in addressing the land and water quality problems associated with these unreclaimed manganese mines. TVA's reclamation work on these AML sites is part of the agency's overall effort to seek resolution of all major water resource problems in the South Fork of the Holston River Basin (TVA 1985). For example, TVA is also working with farmers to control agricultural nonpoint pollution sources through use of best management practices and with homeowners to control or restore failing septic tank drain fields. The project also addressed the reclamation of unreclaimed sand mines that were causing offsite environmental problems.

Environmental Problems

The major environmental problem associated with abandoned manganese mines is excessive soil erosion and subsequent sedimentation of receiving waters. The effect of sedimentation from AML on streams, rivers, lakes, reservoirs and hydro-power operations in the Tennessee Valley has been previously reported (Muncy and Bollinger 1984, Muncy 1985, and Muncy 1986A).

The major watersheds adversely impacted by large amounts of sediment from these lands are the South Fork of the Holston and Watauga Rivers. These rivers, along with the North and Middle Forks of the Holston, form the Holston River. The tributary watersheds of the South Fork of the Holston and Watauga Rivers where most of the mining occurred includes: Georges Branch, Bishop Branch, Buzzard Den Branch, Cressy Creek, Jerrys Creek, and Staley Creek (sand) in Virginia; and Beaverdam Creek, Laurel Creek, Roan Creek, Doe Creek, Stony Creek, and Blue Spring Branch in Tennessee. Several of these streams are high quality headwater trout streams that support good fisheries. Also, the State of Virginia's Buller Fish Hatchery near Thomas Bridge encountered adverse water quality problems that were attributed to upstream mines located on Georges Branch and Bishop Branch watersheds.

Project Area

The mining for manganese in the Tennessee River watershed occurred in Smyth and Washington Counties, Virginia, and Johnson and Carter Counties, Tennessee. The AML sites are located from Sugar Grove, Virginia southwest to Mountain City and Elizabethton, Tennessee. Additional lands were mined near Cedar Springs, Virginia in Smyth and Wythe Counties. These other lands are not part of the project area because they are located outside the watershed of the Tennessee River.

Most of the project minesites in Virginia are clustered on the south slopes of Brushy Mountain in the Jefferson National Forest northwest of Sugar Grove. The old minesites are also located on the north slopes of the Iron Mountains in Virginia and Tennessee. Other locations in Tennessee include Forge Mountain, Doe Mountain, Dry Run Mountain, and the lower south slopes of Holston Mountain. Some of the Tennessee AML sites are located in or near the Cherokee National Forest.

The four-county, two-state project area is located in the Unaka Mountains. The Unaka Mountains are a major unit of Cambrian rocks in the northwest segment of the southern section of the Blue Ridge Physiographic Province (Fenneman 1938). The project area is adjacent to and drains into the Ridge and Valley province. Both provinces are divisions of the Appalachian Highland Region. The project area covers about 650 square miles; 12 miles wide and 54 miles in length. The topography is rolling to mountainous and minesite elevation ranges from 2,000 to 3,300 feet. The climate is characterized by cold winters and mild summers. Monthly mean temperatures range from 33 degrees (Fahrenheit) in January to 74 degrees in July (USDC, NOAA 1982A and 1982B). Precipitation averages 49 inches per year with monthly extremes of 3 inches in October and 5 inches in July (USDC, NOAA 1982A and 1982B). However, much of the rain is in the form of intense storms. Droughts of sufficient intensity to limit tree growth are most likely to occur in June, September, and October. However, the project area, along with the entire southeastern U.S. has experienced major, extended droughts over the last four years. These droughts were especially severe during the 1986 and 1988 growing seasons.

Most of the old minesites were in forest cover prior to mining. The three major forest cover types found in this area include white pine, oak-hickory, and oak-pine (SAF 1980).

Project Cooperators

TVA cooperated with private landowners, U.S. Forest Service (USFS), U.S. Soil Conservation Service (SCS), Virginia Division of Mineral Mining (VDMM), Virginia Game Commission (VGC), and Tennessee Department of Health and Environment (TDHE) in achieving on-the-ground reclamation. Throughout project implementation, TVA sought and obtained financial and in-kind contributions from landowners and State and Federal agencies.

In Virginia, the USFS, TVA, and VGC joined together to reclaim the old minesites in the Jefferson National Forest near Sugar Grove in Smyth County (figure 2). In this cooperative effort, 107 acres were intensively reclaimed and remedial treatments were also conducted (USDA, FS 1983). TVA secured an agreement with a private landowner to reclaim 36 acres in the same ore deposit near Sugar Grove.

TVA also worked with the USFS to treat 5 acres on the Mount Rogers National Recreation Area (MRNRA) near Teas in Smyth County. In the 1960s, the USFS also reclaimed 169 acres (in the Tennessee Valley) on the MRNRA around Sugar Grove in Smyth County. The State of Virginia with its limited reclamation bond interest monies reclaimed 16 acres near Damascus in Washington County and 5 acres near Thomas Bridge in Smyth County. Virginia also worked on a 2 acre minesite (included in the 107 acres above) near Sugar Grove in Smyth County.

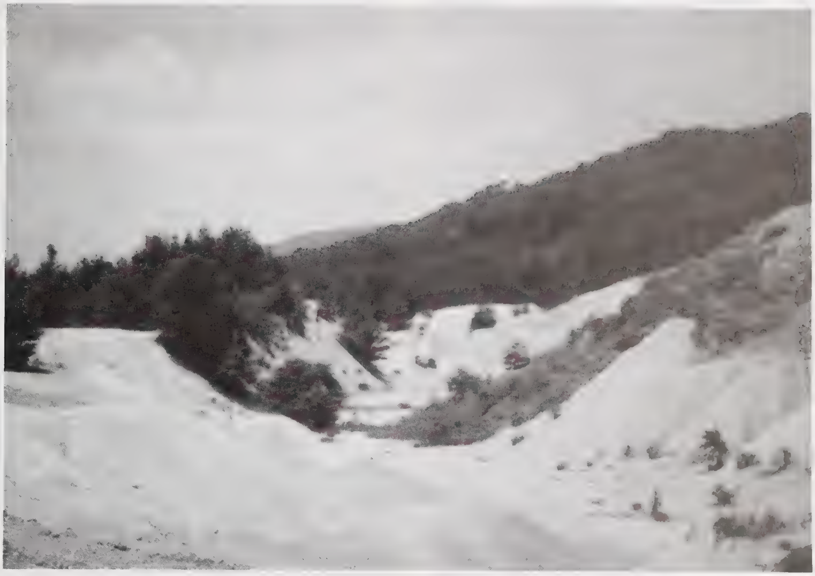
In Tennessee, TVA secured agreements with 23 private landowners to reclaim 107 acres scattered throughout Johnson County and 21 acres east of Elizabethton in Carter County. The landowner agreements authorized the reclamation work and provided for the protection of the reclaimed site for five years. Certain landowners assisted with the reclamation efforts by providing in-kind services such as heavy equipment operation and storage facilities. In the early 1960s, a farmer reclaimed a 5 acre minesite on his property near Blue Spring in Carter County. This site now supports a healthy loblolly pine (Pinus taeda) stand.

The State of Tennessee provided special funding to establish a reclamation demonstration on a minesite (19 acres included in the 107 acres above) near Laurel Bloomery in Johnson County. The two landowners of this demonstration site assisted financially. The SCS prepared the technical plan and administered the sediment control and site preparation work. TVA conducted the revegetation work. Tennessee and SCS also reclaimed a 3 acre minesite near Crandull in Johnson County.

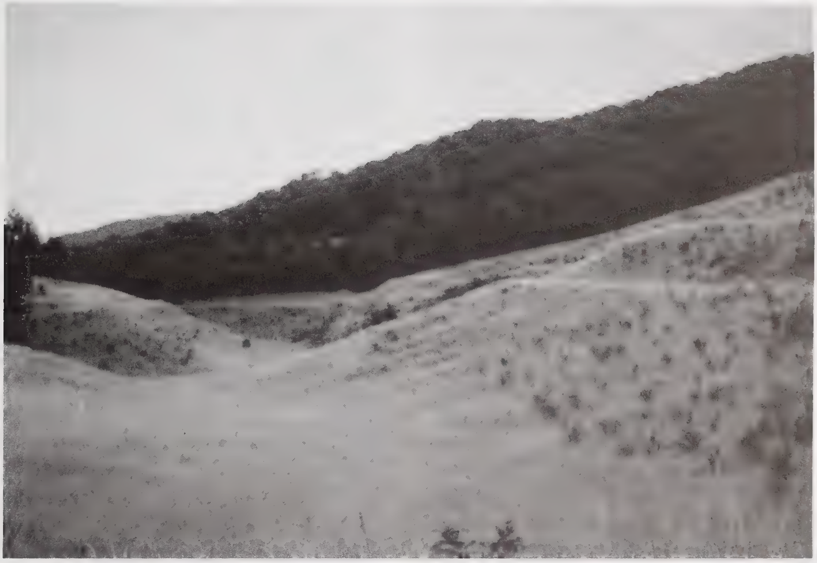
In the mid 1960s, the USFS reclaimed 6 minesites totaling 42 acres located on the Cherokee National Forest near Unaka and Blue Spring in Carter County. The USFS also reclaimed 2 minesites covering 5 acres on the Cherokee National Forest near Sutherland and Laurel Bloomery in Johnson County.

Characteristics of Minesites

The AML sites are generally on dry upland sites on the mid-to-lower slopes of various mountains. Moist conditions exist within subsites of the AMLs and along drainages. The premining natural slopes ranged from moderate to steep. The postmining physical configuration varies from site to site, but generally consists of outslopes that were created by pushing or casting spoil downslope, randomly located spoil piles, and open cuts with small highwalls or steep banks.



A. Before reclamation of the Georges Branch mine in Smyth County, Virginia, June 1985.



B. After cooperative USFS and TVA reclamation of the Georges Branch mine in Smyth County, Virginia, July 1987.

Figure 2. Before and after reclamation of a minesite on the Jefferson National Forest.

Most surface water drains offsite since few depressions exist for water to impound. Severe sheet, rill, and gully erosion occurred over the years. Sheet erosion was so intensive that it exposed the roots of numerous volunteer woody-stem species. Gullies are common. During major rainfall events, soil splashes upwards of two feet on volunteer plants because of the lack of adequate vegetative cover. Most of the original access roads were not properly constructed and have been impassable to rubber-tired equipment for years. The access roads washed out because of the lack of proper water control devices such as culverts, water turnouts, and drainage ditches.

No soil structure remained after mining, and what little topsoil existed either eroded away or was hauled away with the manganese to be processed. The remaining spoil material at most minesites consists of few rock fragments and is composed of sand, clay, and silt particles in descending order. A textural analysis classifies the spoil material primarily as a clay loam. The spoil contains limited organic matter and is nutrient deficient. Spoil samples were randomly collected from several minesites. Analysis indicated pH in the top six inches ranged from 4.7 to 6.3. Average pH is identified at 5.3. The spoil is a reddish coloration with various intermingled darker shades of red, brown, and gray. In the winter, subsurface ice crystal formation or frost-heaving is common.

The minesites that did not naturally revegetate have a combination of limiting factors that created a harsh growing environment for plants. Such limiting factors include steep slopes, severe sheet and gully erosion, high surface temperatures during the growing season caused by the semi-dark spoil color, and southernly aspects, infertile and moderately acidic plant-growth media, and frost-heaving.

The minesites that naturally revegetated are supporting both early successional volunteer herbaceous and woody-stem cover, with trees and shrubs dominating. Major woody-stem volunteers include yellow-poplar (Liriodendron tulipifera), Virginia pine (Pinus virginiana), black locust (Robinia pseudoacacia), and red maple (Acer rubrum).

Reclamation Activities

The objective of this on-the-ground land reclamation work was to cost-effectively stabilize the AML sites that were causing offsite environmental impacts. This was accomplished through a reclamation approach TVA has used in reclaiming other AML in the Tennessee Valley region (Muncy 1986C). The reclamation approach stresses correcting problems of surface waterflow and active erosion, returning the land to productive watershed, forest, and wildlife uses, and enhancing overall aesthetic values. The levels of reclamation range from minimum revegetation efforts to intensive water and sediment control, site preparation, and revegetation work.

Water and Sediment Control

Proper surface water drainage patterns were established at minesites and along access roads where grading occurred. For example, in several cases, surface waterflow was diverted back into natural stream courses and away from problem spoil areas. On one extensive minesite slope 3,750 feet of terraces were constructed to intercept runoff and to divert it to wooded buffer areas. Six-hundred feet of solid agricultural polyethylene tubing (soil pipe) was incorporated into the terraces at strategic locations with eight surface inlets to assist in safely moving concentrated terrace flow to the toe of the slope. Other runoff control techniques included small channel stabilization with riprap, diversion and drainage ditches, and grassed waterways. Access roads were properly drained through the use of broad-base dips, water bars or turnouts, culverts, ditches, and outsloping.

Sediment control was achieved by constructing perforated drop inlet sediment basins, small depressions, small check dams, and filter strips. Excelsior backed erosion control netting was used to stabilize several erosive slopes.

Grading and Site Preparation

Certain minesites needed to be graded with a bulldozer to provide a suitable environment for vegetation establishment. Objectives of the grading were to open up access roads, eliminate rills and gullies, bury debris, cover nonfertile material, create gentle slopes, establish proper surface water drainage patterns, and prepare seedbeds. Graded surfaces were not backbladed to a smooth finish since this practice impedes successful revegetation.

Seedbeds were prepared on accessible sections of selected minesites by conventional methods such as disking and dragging. Where grading was conducted, final surfaces were left semi-rough to provide microsites to trap amendments and provide favorable conditions for seed catchment, germination and plant growth. The rough spoil is also more conducive to tree planting and allows for better infiltration of rainfall. Several acres at one minesite were subsoiled with a bulldozer to a depth of about 24 inches. This technique breaks up crusted, compacted and impervious subsoil layers which creates improved conditions for tree and shrub planting and increases water infiltration. "Tracking in" with a bulldozer was conducted on steep slopes to establish a seedbed and prevent sheet erosion. On inaccessible minesites, aerial seeding was done during late winter to take advantage of loosened soil from freezing and thawing periods.

Revegetation

The primary goal of this project was to reestablish herbaceous and woody-stem species over the AML for erosion control purposes. This was accomplished through identifying individual minesite treatment needs and employing a proper revegetation scheme within the scope of available resources. Major revegetation activities consisted of applying soil amendments, seeding, mulching, tree and shrub planting, and follow-up maintenance.

Soil amendments. Liming was conducted on selected minesites where spoil acidity was of concern in vegetation establishment. However, minesite pH was generally within acceptable limits for successful revegetation. Proven acid-tolerant plant species were generally used to assure success. Typical pulverized agricultural lime was spread by conventional spreader trucks and pelletized agricultural lime was aerially distributed by helicopter. The aerial lime application was conducted only on extremely critical and inaccessible sites because of the high cost of the material ($50 per ton).

A blend of three high analysis fertilizers was used for ground cover establishment whether hydroseeded or aerially applied. It included 150 pounds per acre of 0-0-60 or potash, 300 pounds per acre of 18-46-0 or diamonia phosphate, and 50 pounds per acre of 45-0-0 or urea.

Seeding. Seeding of grasses and legumes and certain tree species was done by two broadcast methods, hydroseeding and helicopter seeding. Hydroseeding occurred on most minesites that were graded, along with certain other selected and accessible sites. Aerial seeding was the only practical and environmentally acceptable way to treat the inaccessible minesites spread out over the four mountainous counties. This saved the costs of opening up access roads, but more importantly, it circumvented the offsite environmental damages associated with reconstructing several miles of roads. Aerial seeding is also cost-effective (Muncy 1986B).

Two seed mixtures were primarily used. Mixture number 1 included Kentucky-31 tall fescue (Festuca arundinacea), birdsfoot trefoil (Lotus corniculatus), kobe lespedeza (Lespedeza striata), perennial ryegrass (Lolium perenne), redtop (Agrostis gigantea), and scarified black locust. Mixture number 2 consisted of interstate sericea lespedeza (Lespedeza cuneata), Kentucky-31 tall fescue, kobe lespedeza, weeping lovegrass (Eragrostis curvula), and scarified black locust. Mixture number 1 was applied by hydroseeders at the rate of 67 pounds per acre. Minesites that were aerially seeded received 75 pounds per acre of mixture number 2. Both mixtures provided excellent cover.

Mulching. Fifteen-hundred pounds per acre of quality wood fiber mulch with tackifier was used on all minesites that were hydroseeded. The tackifier is premixed with the hydromulch fibers to better enable the mulch to remain in place on treatment areas, including steep slopes. Hay was used to mulch some touch-up areas. On several steep slopes excelsior backed erosion control netting was used. The netting was secured with 6-inch metal pins. No mulching was conducted on minesites that were aerially seeded. Aerial treatments were completed in late winter and early spring, in time to take advantage of normal spring rainfall.

Tree and shrub planting. The AML sites were overplanted in bare root stock trees and shrubs beneficial to wildlife. The seedlings were planted by hand with hoedads because of the steep topography and the generally scattered, small minesites. A slow release fertilizer tablet was inserted adjacent to each planted seedling. Both 9-gram (22-8-2) and 21-gram (20-10-5) tablets were used. The 21-gram tablet reportedly improves seedling survival and growth significantly (Berry 1979). A fertilizer tablet supplies major nutrients needed by a transplanted seedling for two or three growing seasons. The tree seedlings were planted on a 6- by 6-foot offset spacing. This spacing is easily achieved and understood by tree planters and adequately allows for mortality losses. The shrub seedlings were planted on closer spacings in clumps, contour borders, and along edges for soil stabilization and enhanced wildlife habitat benefits. All seedlings were dipped in a synthetic soil moisturizer prior to planting and planted deeper than normal to compensate for potential sheet erosion and frost-heaving. The seedlings were 1-0, except for eastern white pine (Pinus strobus) which were 2-0.

Efforts were made to match species to subsite conditions and needs. The general planting pattern included black locust on the steep slopes and severe gullies, eastern white pine on the flats and better spoils, and autumn olive (Elaeagnus umbellata) and shrub lespedeza (Lespedeza bicolor) in pockets and selected rows to benefit wildlife. The herbaceous cover was not established dense enough to be considered a competitive threat to the trees and shrubs. This tree-herbaceous combination is possible because the amount of rainfall normally received is almost 50 inches annually.

Species planted included 63,000 black locust, 37,000 eastern white pine, 27,000 autumn olive, 8,000 shrub lespedeza, 7,000 Virginia pine, 6,000 green ash (Fraxinus pennsylvanica), and 5,000 eastern cottonwood (Populus deltoides). Higher than expected mortality rates occurred because of the extended drought.

Maintenance. The treated minesites received at least one maintenance aerial application of 12-24-24 fertilizer. Some of the harsher minesites received two and three supplemental aerial fertilizations. Other remedial work included spot tree and shrub planting, terrace clean out, and touch-up hand cyclone seeding and fertilizing. Several access roads were blocked off to vehicular traffic to prevent unnecessary damage from off road "joy riders." The most effective closure method found to stop four-wheel drivers is by constructing a double dipped earth berm or double tank trap.

Project Costs

Costs varied by reclamation activity. An itemized cost listing by activity follows: (1) grading with an International TD25C bulldozer, $90 per hour, (2) hydroseeding 67 pounds of an acid-tolerant seed mixture, 500 pounds of high analysis fertilizer, and 1,500 pounds of quality wood fiber mulch, $700 per acre, (3) aerially spreading 2 tons of pelletized lime, $377 per acre, (4) aerially spreading 75 pounds of an acid tolerant seed mixture and 500 pounds of high analysis fertilizer, $200 per acre, (5) aerially spreading 500 pounds of high analysis fertilizer, $100 per acre, (6) planting woody-stem bare root seedlings and inserting 21-gram fertilizer tablets, $275 per thousand, and (7) securing excelsior backed erosion control netting on steep slopes $6,000 per acre.

An approximate breakdown of dollars provide by project cooperators include TVA $247,000, USFS (Wythe Ranger District) in Virginia $149,653, USFS (MRNRA) in Virginia $106,756, VGC $750, VDMM $63,850, USFS (Watauga Ranger District) in Tennessee $25,608, TDHE $4,835, and voluntary landowner assistance $6,583. The total project cost was $605,035. Average cost was $1,161 per acre. TVA's financial support was provided by its Water Quality Department and project implementation by its Reclamation Program.

Conclusion

Abandoned manganese mine lands in southwest Virginia and northeast Tennessee were considered a major nonpoint source of pollution to receiving waters. Through cooperative efforts with State and Federal agencies and private landowners, most of the environmental problem lands have been stabilized and returned to productive watershed, forest, and wildlife uses, along with greatly improving their aesthetic values. The on-the-ground reclamation work was accomplished through a practical cost-effective approach. A total of 72 separate minesites covering 521 acres were successfully reclaimed by TVA and cooperators. Only 14 acres remain in need of treatment.

Acknowledgements

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GROUNDWATER HYDROLOGIC REGIMES WITHIN RECLAIMED SURFACE COAL MINED LANDSCAPES IN ALBERTA[1]

by

S. R. Moran, M. R. Trudell, and T. M. Macyk[2]

Abstract. Between 1979 and 1988, the Plains Hydrology and Reclamation Project (PHRP) investigated interactions of groundwater, soils, and geology and successful reclamation of surface coal mines in the plains of Alberta. Among the objectives of the study was to document the processes by which a steady-state hydrologic regime was re-established following reclamation and to determine the rate at which steady-state conditions were attained. Instrumentation was installed in spoil at two study areas: the Battle River area, which included Diplomat, Vesta and Paintearth Mines, and the Wabamun area, which included the Highvale and Whitewood Mines. Our work demonstrated that the processes by which water enters the spoil and the rate at which the post-reclamation steady-state equilibrium hydrologic regime is established differ both within and between mine sites depending on the hydraulic conductivity of the spoil and the landscape setting within the reclaimed terrain. In lowland settings at mines characterized by high permeability spoil, steady-state equilibrium conditions are established within 5 to 10 years of regrading. In upland settings at mines characterized by low permeability spoil, on the other hand, many decades are required to establish steady-state equilibrium conditions.

Introduction

Between 1979 and 1988, the Plains Hydrology and Reclamation Project (PHRP) investigated interactions of groundwater, soils, and geology and successful reclamation of surface coal mines in the plains of Alberta. Among the objectives of the study was to document the processes by which a steady-state hydrologic regime was re-established following reclamation and to determine the rate at which steady-state conditions were attained. Instrumentation was installed in spoil at two study areas: the Battle River area, which included Diplomat, Vesta and Paintearth Mines, and the Wabamun area, which included Highvale and Whitewood Mines (Figure 1). The major focus of our work was at the Battle River area with minor input from the Wabamun area.

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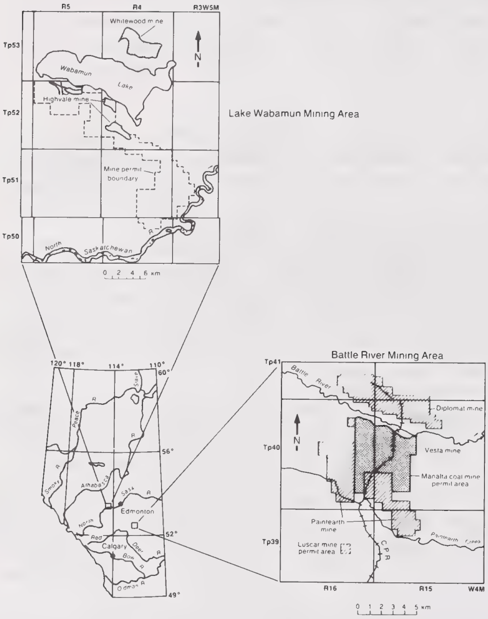

Figure 1. Location of Battle River and Wabamun study areas of the Plains Hydrology and Reclamation Project.

At Vesta Mine, 27 sites were instrumented with nests of multiple standpipe piezometers. Piezometers were installed in individual holes that were drilled to the desired depth, generally with a truck-mounted, solid-stem auger. Piezometers were generally a 5-cm PVC riser pipe with a tip consisting of a length of commercially slotted pipe. The piezometer tip was covered with frac sand, then capped with about 0.5 m of bentonite pellets. In most cases, the hole was then backfilled with drill cuttings. Neutron-probe access tubes were installed at 14 of the instrumented sites and infiltration tests were conducted at one site. In addition, three ponds were instrumented to monitor pond level and seepage. At Diplomat Mine, 32 sites were instrumented with multiple piezometer nests; neutron-probe access tubes were installed at 14 of these sites, and infiltration tests were conducted at three sites. Five ponds were instrumented to monitor pond level and seepage. At both mine sites, the majority of the instrumentation is in lowland settings but upland settings are well represented.

Our work demonstrated that the processes by which water enters the spoil and the rate at which the post-reclamation steady-state equilibrium hydrologic regime is established differ both within and between mine sites depending on the hydraulic conductivity of the spoil and the landscape setting within the reclaimed terrain. This paper presents the spoil resaturation model that was developed from the PHRP project work. The two major controlling factors, hydraulic conductivity and landscape setting, are discussed first. The majority of the paper is devoted to quantification of groundwater recharge from various sources in the two major landscape settings and in the two types of spoil. Finally, we present a brief discussion of the implications of the post-mining hydrologic regime for agricultural use of reclaimed landscapes.

Acknowledgements

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project and in preparation of this paper.

Parameters Controlling Hydrologic Processes in Reclaimed Terrain

Hydraulic Conductivity of Mine Spoil

Hydraulic conductivity was determined using single-well response tests following the method of Cooper and others (1967) and Hvorslev (1951). Hydraulic conductivity of mine spoil is highly variable, ranging over as much as six orders of magnitude within individual mines (Figure 2). Hydraulic conductivity of mine spoil is generally low, with the higher values that do occur located either at the base of the spoil or where sandier or more cemented overburden material is concentrated in the spoil. Spoil derived from glacial till, such as at Diplomat and Whitewood Mines, has hydraulic conductivity values that are about 1.0 to 1.5 orders of magnitude higher than those of spoil derived from bedrock, such as at Vesta, Paintearth, and Highvale Mines (Figure 2). Spoil derived from overburden in the Ardley Coal Zone (Highvale and Whitewood Mines), has hydraulic conductivity values that are from 2.0 to 3.0 orders of magnitude higher than those of the in the Lower Horseshoe Canyon Coal Zone (Vesta, Diplomat, and Paintearth Mines) [Figure 2].

The spoil at Vesta and Paintearth Mines consists largely of sodic shale, claystone, and siltstone with a minor admixture of glacial till. Initially, the spoil has a high secondary porosity of as much as 20 to 30% and a relatively high hydraulic conductivity. As the spoil becomes resaturated, however, the sodic bedrock material begins to swell and slake (Dusseault and others, 1988) causing the hydraulic conductivity to decrease dramatically to the low values indicated in Figure 2. At Diplomat Mine, on the other hand, the spoil consists almost entirely of glacial till with minor admixtures of sodic bedrock in places. Although the spoil compacts readily and relatively rapidly assumes density values very similar to the premining state (Pauls and others, in preparation), the hydraulic conductivity of the spoil is considerably higher than at Vesta Mine (Figure 2).

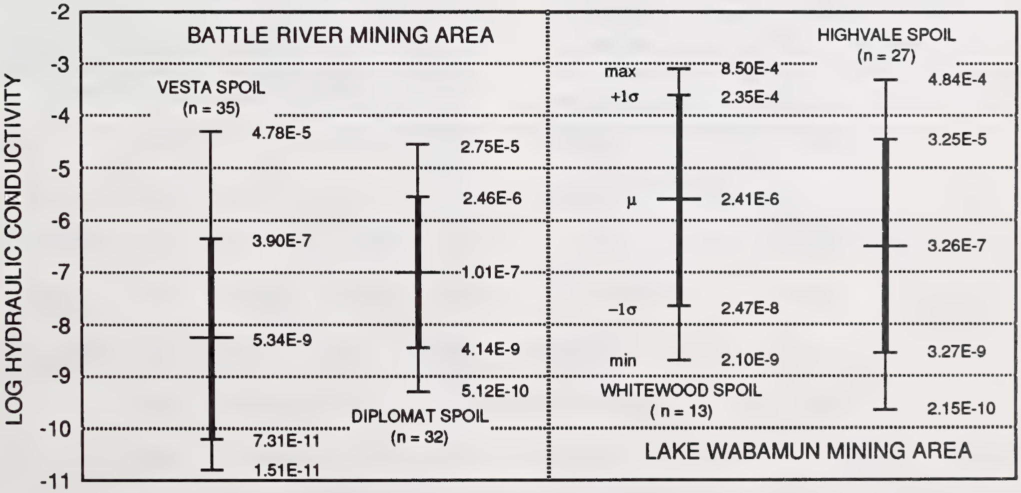

Figure 2. Hydrologic Conductivity (m/s) of Mine Spoil in Central Alberta.

Landscape Settings in Reclaimed Terrain

Two distinctly different hydrologic regimes have been recognized in reclaimed surface-mined landscapes, (1) upland settings and (2) lowland settings (Figure 3). Upland settings, which constitute the majority of reclaimed areas, are generally situated above the premining landscape grade and are characterized by flat to undulating terrain. Numerous small oval depressions, which are about 10 to 20 m wide by 20 to 50 m long and as much as 0.5 m deep, dot the landscape. These depressions, which typically occupy from five to ten percent of the reclaimed surface, form by differential subsidence, which accompanies resaturation of the spoil (Dusseault and others, 1985). During spring melt and heavy summer rain storms these depressions capture water to produce ponds. Ponding is generally ephemeral and tends to be of limited areal extent, with the ponds perched above and not connected to the water table (Figure 3).

Lowland settings, which constitute more restricted areas within reclaimed landscapes, are generally situated at or below the premining landscape grade. These settings generally occupy a greater proportion of the reclaimed landscape in older mining areas than in modern mine sites. Lowland settings develop wherever the premining overburden was thin, generally less than about 4 to 5 times the thickness of the removed coal, and in the vicinity of final cuts. Lowland settings are characterized by deep depressions that result from mining operations, such as final cuts, access ramps and haul roads. Shallow, broad depressions form in areas of thinner spoil that result where pit orientation changed such that the spoil was cast over an area that is larger than the cut from which it was excavated. In addition, small depressions form through differential subsidence. Considerable ponding of surface water occurs in lowland settings with ponds tending to be permanent or semi-permanent and connected to the water table (Figure 3).

Model of Spoil Resaturation

The model presented in this paper is an interpretive conceptual framework based on our observations. We have measured hydraulic properties of the spoil and monitored water level recovery and response to recharge events for as much as 8 years in a variety of settings within reclaimed landscapes. The hydrologic conditions at these sites

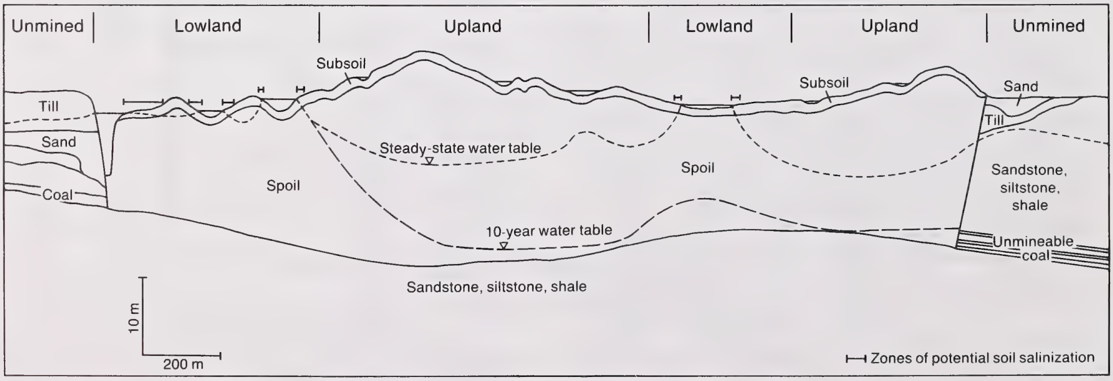

Figure 3. Schematic Diagram Showing Hydrologic Regimes in Reclaimed Landscape.

ranged from immediate post-reclamation conditions to a stable steady-state post-mining regime.

Initial Post-Mining Hydrologic Regime

During surface mining of coal in the plains of Alberta, the bedrock and unconsolidated sediment that comprise the overburden is removed by draglines or shovels and cast backward into the previous pit from which the coal has been removed. In most areas, all but the uppermost several metres of the overburden was saturated with groundwater prior to disturbance. The coal itself and overburden sandstones are commonly sufficiently permeable to meet the water supply needs of the largely rural population of the region. In the mining process, the overburden material is broken into fragments of various sizes that are replaced as spoil. As a result of the space between individual fragments, the spoil mass has a lower density than unmined overburden. This "bulking" of the spoil results in the surface of reclaimed areas being elevated above adjacent unmined areas. Depending on the type of material involved and its initial water content, the secondary porosity created by the spaces between spoil fragments ranges from 10 to 30 %. Immediately following placement of the spoil, this secondary porosity is occupied by air, but as organic matter in the spoil is oxidized the air is replaced by CO_2 (Wallick, 1983). As soon as the spoil is reclaimed, and in some cases even before reclamation is complete, water begins to infiltrate the spoil from ponded rainfall and snowmelt. In the early stages of spoil resaturation, lateral inflow from adjacent unmined aquifers makes a significant contribution to spoil resaturation in all landscape settings because of the large hydraulic gradient. With time, the gas in the secondary pore space is displaced by the rising groundwater as the spoil mass once again becomes saturated.

Spoil Resaturation

The process of spoil resaturation is fundamentally different in lowland and upland settings. The rate of spoil resaturation and the rate at which stable steady-state equilibrium conditions are established are governed by the hydraulic conductivity of the spoil. Combining these two factors gives a four component model of spoil resaturation.

Recharge in Lowland Settings with High Permeability Spoil. During the early stages of spoil resaturation, all spoil regardless of composition appears to be characterized by relatively large values of hydraulic conductivity. Groundwater recharge in lowland settings occurs more or less continuously by leakage from both deep and shallow permanent ponds (Schwartz and Crowe, 1987). Ephemerally ponded depressions and infiltration beneath unponded sites also contribute to the recharge in lowland settings (Trudell and others, 1986). Leakage of water from ponds is initially very rapid resulting in rising water levels that saturate the spoil at rates as great as 1 m/year. In spoil consisting largely of till or non-sodic bedrock, the hydraulic conductivity remains high. Rapid resaturation of the spoil continues until the rising groundwater level causes the hydraulic gradient to decrease and pond leakage slows. In mine sites with high permeability spoil, recovery of groundwater levels to the stable post-mining steady-state configuration is rapid, generally requiring no more than 5 to 10 years.

At the western end of Diplomat Mine, the PHRP project instrumented an area of about 1 490 000 m^2 of which about 807 500 m^2, or about 54% comprises lowland. Within the lowland, about 20% of the area is ponded. One large, deep pond occupies about 67 300 m^2 (8.3% of the area); small, shallow ponds occupy about 50 000 m^2 (6 % of the area); and about 5% of the area is occupied by ephemeral ponds during snowmelt and after heavy rain. Total recharge in this instrumented site is calculated as about 15 265 m^3 per year, which is equivalent to a recharge rate of 1.89 x 10^{-2} m^3/m^2 (Table 1). Large, deep ponds account for 57% of the recharge with non-ponded areas second most important, accounting for 20% of the recharge.

Recharge in Lowland Settings with Low Permeability Spoil. In lowland settings where the spoil contains abundant sodic bedrock, slaking and swelling of the spoil reduces the initially large hydraulic conductivity to much lower values. This results in a significant reduction in the rate of pond leakage and spoil resaturation. Recovery of groundwater levels to the stable post-mining steady-state configuration is slow, requiring at least several decades in mine sites with spoil having low hydraulic conductivity values.

At the western end of Vesta Mine, the PHRP project instrumented an area of about 942 500 m^2 of which about 180 000 m^2, or about 20% comprises lowland. Within the lowland, about 28% of the area is ponded. One large, deep pond occupies about 30 500 m^2 (17% of the area); two small, shallow ponds occupy about 12 850 m^2 (7.1% of the area); and about 5% of the area is occupied by ephemeral ponds during snowmelt and after heavy rain.

Table 1.

	Area		Seepage Rate	Recharge	
	(m^2)	%	(m^3/m^2)	(m^3)	%
VESTA LOWLAND					
SMALL PONDS	12,850	7.1	0.1096	1408	61.1
NON-PONDED	127,735	71.0	0.0035	447	19.4
LARGE POND	30,425	16.9	0.0083	252	10.9
EPHEMERAL PONDS	9,000	5.0	0.0220	198	8.6
TOTAL	180,000		0.0128	2305	
DIPLOMAT LOWLAND					
LARGE POND	67,300	8.3	0.1285	8645	56.6
NON-PONDED	649,825	80.5	0.0047	3054	20.0
EPHEMERAL PONDS	40,375	5.0	0.0583	2352	15.4
SMALL PONDS	50,000	6.2	0.0243	1215	8.0
TOTAL	807,500		0.0189	15266	
VESTA UPLAND					
NON-PONDED	712,875	93.5	0.0035	2495	54.3
SMALL PONDS	11,500	1.5	0.1096	1261	27.4
EPHEMERAL PONDS	38,125	5.0	0.0220	839	18.3
TOTAL	762,500		0.0060	4594	
DIPLOMAT UPLAND					
NON-PONDED	614,250	90.0	0.0047	2887	50.6
EPHEMERAL PONDS	34,125	5.0	0.0583	1988	34.9
SMALL PONDS	34,125	5.0	0.0243	829	14.5
TOTAL	682,500		0.0084	5704	

The spoil in the lowland area, which was mined and reclaimed between 1970 to 1975, ranges in thickness from about 12 m to 22 m. By 1981, when the site was instrumented, the groundwater level in the area was about 8 m above the base of the spoil, indicating an average water-table rise of about 1 m/year. Comparison of the density of the spoil in this area with that of unmined overburden indicates that secondary porosity is about 15% to 20%. On this basis we conclude that average total recharge in this area was between 0.15 and 0.20 m^3/m^2/year for the first 8 years following reclamation. Because the water table has generally been constant or has declined slightly since 1981, we conclude that the rate of spoil resaturation has decreased significantly from its initial value. The

PHRP project studied leakage from permanent ponds in this area in 1984 and 1985 and from ephemerally ponded depressions in 1986. We calculated a total recharge flux was about 1.275×10^{-2} m^3/m^2 (Table 1). We conclude from this that the average recharge rate between 1973 and 1980 was about 10 to 15 times as great as it was between 1981 and 1988. Small permanent ponds account for 61% of the recharge, with non-ponded areas second most important, accounting for 19% of the recharge.

Upland Settings with High Permeability Spoil. In upland settings, groundwater recharge occurs almost entirely by infiltration beneath unponded sites over the entire landscape and beneath ephemerally ponded depressions and the few shallow permanent ponds that form in larger subsidence depressions. Where the hydraulic conductivity of the spoil is high, steady-state equilibrium is achieved in 10 to 15 years depending on the thickness of spoil and climatic conditions.

Upland settings were instrumented in two areas of Diplomat Mine. About 682 500 m^2, or 46% of the instrumented study area at the west end of the mine consists of upland areas. Three small instrumented sites in the eastern part of Diplomat Mine also characterize upland settings. About 5% of the instrumented upland area at the western end of Diplomat Mine is occupied by permanently ponded depressions. Another 5% of the entire upland area is characterized by depressions that are ponded during snow melt and after heavy rain storms. Total recharge in the instrumented upland setting at Diplomat Mine is calculated at 5704 m^3 per year, which is equivalent to a recharge rate of 8.36×10^{-3} m^3/m^2 (Table 1). Non-ponded sites account for 51% of the recharge with ephemeral ponds accounting for 35% of the recharge.

Upland Settings with Low Permeability Spoil. In upland settings where the hydraulic conductivity of the spoil is low, a much longer period is required to reach steady-state conditions, at least several decades. As in lowland settings, the hydraulic conductivity of the spoil is initially high and water infiltrates rapidly beneath small depressions. As the spoil becomes saturated, slaking and swelling cause hydraulic conductivity to decrease. Small depressions that initially drained rapidly become the site of larger perched ponds as the rate of seepage declines and as a result of increased differential subsidence resulting from the seepage. Recharge from these depressions declines as a greater proportion of the water they contain is returned to the atmosphere by evaporation and evapotranspiration.

Upland settings were instrumented in two areas of Vesta Mine and at Paintearth Mine. About 762 500 m^2, or 80% of the instrumented study area at the west end of Vesta Mine consists of upland areas. An upland area of about 300 000 m^2 in the eastern part of Vesta Mine was instrumented with three piezometer nests and two neutron-probe access tubes. An upland area of about 500 000 m^2 at Paintearth Mine was instrumented with three piezometer nests and six neutron-probe access tubes. About 5% of these instrumented upland areas are occupied by depressions that are ponded during snow melt and after heavy rain storms. Permanently ponded depressions are present but occupy no more than about another 1.5% of the entire upland area. Total recharge in the instrumented upland setting at Vesta Mine is calculated at 4594 m^3 per year, which is equivalent to a recharge rate of 6.0×10^{-3} m^3/m^2 (Table 1). Non-ponded sites account for 54% of the recharge with small permanent ponds second most important, accounting for 27% of the recharge.

Steady State Equilibrium Hydrologic Regime

The significance of the model of spoil resaturation that is presented in this paper does not lie in the quantitative estimates of recharge rates. Rather, it lies in the importance of relative differences in recharge in various settings in determining the post-mining hydrologic regime. The model suggests that recharge in lowland settings is about twice that in upland settings, regardless of hydraulic conductivity. Furthermore, the model indicates that in east-central Alberta, this difference in recharge rate is sufficient to produce differences in the post-mining hydrologic regime. Where recharge is less than about 1.5 to 2.0% of the total annual precipitation, groundwater flow is able to remove the water supplied and the water table does not interact with the land surface. Where recharge is about 3.0 to 4.5% of the total annual precipitation, however, groundwater flow is not able to remove the water supplied and the water table rises to the land surface.

The steady-state hydrologic regime in reclaimed landscapes is essentially the same as that prior to mining and in adjacent undisturbed settings. The principal difference lies in the dynamics of ephemerally ponded upland depressions. In reclaimed landscapes, these depressions are expected to be subject to more severe seasonally wet conditions than in unmined landscapes. Water infiltrating beneath small depressions generally moves downward until it encounters a zone of lower hydraulic conductivity. The greater the depth to such a barrier, the more water can be drained away from the pond in the depression and the quicker the ponding dissipates. Sodic bedrock, which underlies surficial deposits and constitutes a significant hydraulic barrier in most mining areas in the plains of Alberta, is encountered at variable depths but in places is quite deep. In the Battle River mining area, for example, as much as 10 m of glacial till overlies sodic bedrock in parts of the unmined landscape. Subsequent to mining, only 1.0 to 1.5 m of till is generally replaced over the dominantly bedrock-derived spoil. The decrease in permeability at the top of the spoil is expected to impede downward infiltration and result in perching of ponds above the regional water table.

The steady-state water table in lowland settings is close to the land surface over much of the area, generally being no more than 1 m to 3 m deep (Figure 3). Once the post-mining equilibrium is established, the large ponds are sites of groundwater discharge, at least during part of the year. In upland settings, the steady state water table is at considerable depth below the land surface, at least 5 m to 10 m metres below the surface in most areas. The water table approaches the land surface only beneath larger permanent and semi-permanent upland ponds (Figure 3).

On the basis of observations within the reclaimed study sites and in adjacent unmined sites, it is expected that soil salinization will develop in lowland settings where the steady-state water table is within about 1.0 m of the land surface (Moran and others, 1986). The combination of seasonally wet conditions and saline soils is expected to significantly restrict the agricultural capability of a relatively large proportion of lowland settings in reclaimed landscapes. At Diplomat Mine, about 139 000 m^2 (13.9 ha), which represents 17% of the total lowland area, is expected to develop seasonally wet conditions and saline soils. This area, combined with areas of permanent ponds results in about 30% of the lowland area having appreciably reduced capability for agriculture relative to the remainder of the reclaimed area. Limited areas of saline soils have also been observed to be developing around larger depressions in upland settings.

At both Diplomat and Vesta Mines, ponds or sloughs were present in the premining landscape. At Diplomat Mine, the premining landscape was characterized by numerous small sloughs scattered across the area, reflecting the overall poorly-integrated drainage pattern. In some cases, ponds in the reclaimed landscape are in approximately the same location as the larger premining sloughs. In most cases, however, the location of post-mining ponds has been controlled by the mining process or by differential subsidence. At Vesta mine, the situation is similar, but with fewer ponds in both premining and reclaimed settings. Although the area of ponding at both mine sites was generally similar before and after mining, the ponds in the post-mining landscape are generally fewer, larger, deeper, and tend to be more permanent, than ponds in the premining setting. The net result is that the surface hydrology and distribution of sites of groundwater recharge and of soil salinity in reclaimed land should be more or less similar to the natural landscape.

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GEOMORPHIC RESPONSES OF NATURAL AND RECLAIMED HILLSLOPES TO PRECIPITATION EVENTS IN WYOMING[1,2]

by

Terrence J. Toy[3]

Abstract. Runoff and sediment data were collected from plots on two natural and reclaimed hillslopes at the Glenrock Coal Company. Runoff from the newly reclaimed site exceeded that from the natural sites despite lower average precipitation intensities; however, runoff from the older reclaimed site was less than from the natural sites. Sediment yield from the newly reclaimed site was much higher than from the natural sites while sediment yield from the older reclaimed site was within the range of that from the natural sites. Sediment concentration of flows from the newly reclaimed site were very high, especially at the beginning of the record, and greatly exceeded those from the natural sites. Again, sediment concentrations from the older reclaimed site were within the range of those from the natural sites. There were significant statistical relations between runoff and sediment yield. The comparison of sediment and soil particle-size distributions suggested selective entrainment and transportation of soil separates. Lastly, available evidence suggested that reclaimed surfaces may approach a semblance of equilibrium, analogous to natural surfaces, in about five years.

ADDITIONAL KEY WORDS: Reclamation success; Geomorphological assessment.

Introduction

Much pertinent literature identifies erosion control as central to the mission of surface-mine reclamation (Hodder, 1975; Dollhopf et al, 1977; Vogel, 1981; Toy and Hadley, 1987). However, the evaluation of reclamation success is commonly based upon qualitative or visual evidence. Herein, rill development on finish-graded surfaces, channel or gullies at the midpoints or toes of hillslopes, and deposits of eroded material at the base of hillslopes, are generally taken as

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[2] Publication in this proceedings does not preclude authors from publishing their manuscripts, whole or in part, in other publication outlets.

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indicators of reclamation problems (Curtis et al, undated). The National Research Council (1981) laments the paucity of actual erosion data for the mined lands of the western United States and the state of affairs is not markedly better for the eastern region.

It is the purpose of this report to present the results of a runoff and sediment yield study conducted on two natural and two reclaimed hillslopes at a surface mine in east-central Wyoming. This research was part of a larger project, also measuring sheetwash erosion and soil creep rates at this same locale; the results of the sheetwash erosion investigation will be available elsewhere (Toy, in press).

The Study Area

Runoff and sediment yield data were collected at the Dave Johnston Mine of the Glenrock Coal Company in east-central Wyoming. This operation is situated near the southern border of the Powder River Basin in the Northern Great Plains Physiographic Province. The surface geology consists of nearly horizontal strata of conglomerates, sandstones, siltstones, shales, and interbedded coal seams deposited in freshwater streams, lakes and swamps, and designated as the Wasatch Formation.

The climate is classified as semiarid, continental with an annual precipitation of approximately 380 mm, of which about 57% is received during the May-September growing season (Toy and Munson, 1978). The estimated rainfall erosivity (R-factor) is 30, according to the U.S. Soil Conservation Service and U.S. Environmental Protection Agency (1977).

The natural vegetation cover consists primarily of shortgrasses and sagebrush, typical of the Northern Great Plains. Common plant species include blue gramma grass (Bouteloua gracilis), western wheatgrass (Agropyron smithii), needle-and-thread grass (Stipa comata), and big sagebrush (Artemisia tridentata).

The undisturbed soils are classified as coarse-loamy and sandy in texture when derived from aeolian parent materials and coarse-loamy to fine-loamy in texture when derived from residual parent materials (Toy and Shay, 1987). Soil erodibility (K-factor) ranges from about 0.24 to 0.49, according to the U.S. Soil Conservation Service and U.S. Environmental Protection Agency (1977).

Method of Investigation

Within this study area, runoff and sediment collection plots were established on two natural and two reclaimed hillslopes. For each pair, one plot was situated on a surface of easterly aspect while the other was situated on a surface of westerly aspect. Both of the reclaimed hillslopes had been graded with a motorscraper. There was no grazing by domestic livestock at any site, although the entire area is subject to periodic grazing by wildlife.

The collection plots were oriented orthogonal to the hillslope contours with a width of 0.75 m and varied in length, in accordance with total hillslope length. To prevent the outflow or inflow of runoff and sediment, plastic tubing with an outside diameter of 2.54 cm (1 in.) was used to delineate each plot. The tubing was fastened to the hillslope surface with wire staples. Soil or surface materials were used to construct a small berm abutting the tubing on the outside of each plot. Lastly, asphalt spray (sold commercially as automobile undercoating) was applied on the inside of the plot to create a seal between the tubing and the soil or surface material. Consequently, the effective plot width was found to average 0.70 m.

A trough was implanted at the downslope terminus of each plot, approximately two-thirds of the distance from the crest of the hillslope. Such troughs or traps vary somewhat in design but most are similar to those described by Young (1960) and Gerlach (1967). Further discussion of this measurement apparatus can be found in Carson and Kirkby (1972), De Ploey and Gabriels (1980), and Dunne (1977). Here, the trough was constructed from roof gutter material with a sheet metal cover and downpipe in the base. The asphalt spray was also used to seal the contact between the trough and the soil or surface material; plot length was reduced by the surface rendered impervious by this spray.

Four runoff and sediment collection barrels were constructed from 208 l (55 gal.) drums and fitted inside with a staff gage. Each barrel was calibrated individually so that the staff gage readings could be accurately converted to volume measurements. These barrels were implanted at the base of the hillslopes upon which the plots were located and leveled so that the staff gages would produce valid readings.

The troughs were connected to the barrels by means of suction hoses. This type of hose is preferable because it will not collapse when empty and, hence, water and sediment will not back up in the hose and trough at the beginning of a runoff event, but flow into the barrel with minimum resistance.

The barrel lids were fitted with a metal "snap-ring" to hold them in place and a slot was cut into the lids to receive the suction hose. Sheet rubber material was used to create a gasket to seal the gap between the lid slot and the suction hose.

Small plastic collector rain gages were placed adjacent to the plots so that the depth of precipitation received at the site could be measured. Precipitation intensity was determined by dividing this depth by the storm duration measured with a recording rain gage at a meteorology station operated by the mine company that averaged a distance of approximately 2 km from the collection plots. It would have been preferable to have a recording rain gage at each site but this was precluded by budgetary constraints.

The runoff and sediment produced from individual precipitation events were transported from the plots, through the troughs, to the collection barrels. Thereafter, and before the next precipitation event, each barrel staff gage and rain gage was read, usually by mine company personnel. At this time, the suction hose was removed from the barrel and the rubber gasket was used to cover the lid slot so that the sample would not be contaminated by other precipitation events or aeolian material. During the next visit to the mine by the principal investigator, the barrels were excavated and the sediment was transferred to small buckets for transport to the laboratory for analysis. Here, the oven-dry weight and particle-size distribution of the sediment samples were determined.

While at the mine the collection barrels were cleaned, replaced, and leveled in preparation for the next runoff event. Likewise, the rain gages were emptied and cleaned. Finally, the plot borders were serviced and new asphalt spray applied at the contacts between the tubing and trough contacts with the soil or surface materials, as needed.

The collection plots were visited in March, June, and September each year throughout the research project. During the March visit, the apparatus was installed and maintained in readiness for the Spring precipitation. Samples were collected during the June and September visits, if a runoff event had occurred. At the end of the September visit, the equipment was winterized.

Characteristics of the Sites

The attributes of the land at the collection plots are summarized in Table 1. The soils of the natural sites contain more sand and less silt and clay than those of the reclaimed sites. The bulk densities of the soils are approximately the same for all sites. It appears that the soils of the reclaimed sites contain slightly more organic matter than those of the natural sites, but a part of the organic matter at the former sites is actually waste coal rather than humus or plant rootlets (Toy and Shay, 1987). The soils of the reclaimed sites are somewhat more acidic than those of the natural sites and this may be due to waste coal as well.

The vegetation cover was measured annually at each site using the point-frame method (Levy and Madden, 1933). The values recorded include both live vegetation and surface litter because each is of geomorphic significance in deterring runoff and erosion. The average cover of the natural sites tends to exceed that of the reclaimed sites, although the highest average cover occurs at one reclaimed site while the lowest average cover occurs at the other reclaimed site. It should be noted

TABLE 1: Site Characteristics

Property	Natural Sites		Reclaimed Sites	
	NNNE	NNNW	RSCE	RNMW
A. Surface Material (top dm)				
1. Particle Size				
Gravel (%)	0.40	1.40	3.44	1.20
Sand (%)	81.82	71.97	49.91	52.82
Silt (%)	6.93	12.37	22.91	19.52
Clay (%)	10.90	14.30	25.82	26.53
2. Bulk Density (gm/cc)	1.427	1.309	1.494	1.294
3. Organic Matter (%)	1.50	1.84	2.34	2.39
4. Soil Reaction (pH)	6.71	7.39	5.59	5.60
B. Vegetation Cover* (%)	63.2	57.4	64.0	33.0
C. Date of Reclamation			1976	1981

* includes live vegetation plus organic litter

that the reclaimed site with the lowest average vegetation cover was planted after commencement of this project and the cover developed from 0 to 59 percent over the five-year period of record.

The dimensions of the runoff and sediment collection plots are compiled in Table 2. Plot length varied depending upon hillslope length. Plot width was constant at 0.70 m. As a result, plot area ranged from 19.60 m^2 to 34.09 m^2. The inclination of the plots on the reclaimed sites were somewhat greater than those on the natural sites. Three plots were installed in July, 1980 with the fourth installed on the newly reclaimed surface in April, 1981.

Results

During the period of record, from 1980 to 1984, runoff and sediment samples were obtained following 7-9 events on the collection plots. The number of samples varies due to the installation of the equipment at the newly reclaimed site after seeding in 1981, and barrel overflow at three locations during a storm in August, 1983. Other runoff events sometimes occurred prior to servicing of the plots, but it was not possible to secure additional samples on these occasions with this apparatus. The measurements for precipitation, runoff, and sediment at each plot are summarized in Table 3. There is considerable variation in the data from plot to plot and from event to event; however, it is only possible to present and discuss the average values at this time.

Precipitation

The average total precipitation per runoff event ranged from 18 to 27 mm. Likewise, average precipitation intensity for these storms ranged from 20.8 to 28.3 mm/hr. Recall that there was probably some error in the intensity data because storm duration was taken from the records at the meteorology station rather than measured on-site.

Runoff

The plots on natural hillslopes, NNNE and NNNW, averaged 2.90 l/m^2 and 3.71 l/m^2 of runoff respectively. Because the totals and the intensities were similar, it does not seem likely that precipitation is responsible for the difference. Hillslope aspect, the particle-size distribution of soils, and vegetation cover are probably responsible for much of the variation. In this geographic region, storms and accompanying winds commonly travel from west to east, driving rain into the

TABLE 2: Runoff/Sediment Collection Plot Dimensions

Dimension	Natural Sites		Reclaimed Sites	
	NNNE	NNNW	RSCE	RNMW
A. Plot length (m)	28.0	48.7	46.2	40.0
B. Plot width (m)	0.70	0.70	0.70	0.70
C. Plot area (m^2)	19.60	34.09	32.34	28.00
D. Plot gradient (%)	11	12	15	18
E. Date of installation	7/80	7/80	7/80	4/81

TABLE 3: Geomorphic Response of Natural and Reclaimed Hillslopes (Mean Values)

	Runoff/Sediment Collection Sites			
	Natural Sites		Reclaimed Sites	
	NNNE	NNNW	RSCE	RNMW
Number of Events	9	8	8	7
Precipitation				
Total (mm)	26	27	18	21
Intensity (mm/hr)	26.2	25.3	28.3	20.8
Runoff (l/m^2)	2.90	3.71	1.70	3.59
Sediment				
Per unit area (g/m^2)	4.5	14.6	6.0	203.9
Concentration (mg/l)	1490.1	3746.3	3516.7	26,377.8
Particle size				
Sand (%)	39.6	30.6	19.5	30.3
Silt (%)	32.9	36.5	34.6	25.8
Clay (%)	26.3	31.5	44.5	43.8

westerly-facing hillslopes. As a result, it seems likely that average droplet impact energy is higher on the hillslopes of westerly aspect than on those of easterly aspect. If so, then surface sealing should be more effective on the westerly-facing hillslope. The particle size analyses show that the soils of the westerly-facing site contain more silt and clay than the soils of the easterly-facing site. Lastly, the vegetation cover on the westerly-facing site is less than on the easterly-facing site. Collectively, it would seem that the westerly-facing surface should possess a lower infiltration capacity than the easterly-facing surface and, therefore, should generate runoff at a faster rate.

The plots on the reclaimed hillslopes, RSCE and RNMW, averaged 1.70 l/m^2 and 3.59 l/m^2 of runoff respectively. It is more difficult to explain the differences in average runoff between these two sites because there were also some differences in the average total and intensity of precipitation. However, it seems unlikely that the dissimilarities in precipitation characteristics are sufficient to account for the two-fold variation in runoff. As with the natural hillslopes, the westerly-facing hillslope again generated the greater volume of runoff. Here, however, the particle-size distributions of the surface materials are quite similar and so this factor can be eliminated as a possible cause. The average vegetation cover is considerably higher on the easterly-facing site. Recall that the westerly site was barren at the initiation of the project but developed a cover of 59% by the end of record. Collectively, it again would seem that the westerly-facing surface should possess a lower infiltration capacity than the easterly-facing surface and, therefore, should generate runoff at a faster rate.

Comparison of runoff generation between the natural and reclaimed sites is complicated by the differences in precipitation characteristics. Additionally, the reclaimed hillslopes are slightly steeper in gradient than the natural hillslopes. Nevertheless, it is interesting to observe the general similarity in runoff rates between the two groups, despite the differences in hillslope gradient, vegetation cover, and surface material properties. In fact, the lowest rate of runoff was recorded at one of the reclaimed sites. The findings are similar to the results of the rainfall simulation experiments of Lusby and Toy (1976) at this study area, but at different field locations.

Sediment Yield

The plots on natural hillslopes, NNNE and NNNW, yielded an average of 4.5 g/m^2 and 14.6 g/m^2 of sediment respectively. Because the westerly-facing hillslope generated the greater volume of runoff, it might be expected that it would likewise produce the greater volume of sediment. With greater volumes of runoff, one would expect greater depth and velocity of runoff, and hence, greater tractive force impinging upon the surface materials of the westerly-facing surface.

There is also some evidence that surface erodibility is higher on the westerly-facing site. The relative paucity of vegetation cover and higher silt content of the soils favor higher erosion rates. However, the Soil Conservation Service (1977) nomograph for estimating soil erodibility (K-Factor) does not indicate substantial differences between these two sites.

The plots on reclaimed hillslopes, RSCE and RNMW, yielded an average of 6.0 g/m^2 and 203.9 g/m^2 of sediment respectively. The average for the latter site was heavily weighted by very high sediment yields early in the period of record while vegetation cover was minimal. Again, the westerly-facing hillslope generated the greater volume of runoff, possessed the lower vegetation cover, and produced the greater volume of sediment. Here, the particle-size distribution and organic matter content of surface materials are similar and so there should not be much difference in soil erodibility at the two sites.

The comparison of sediment yields from the natural and reclaimed sites is again complicated by the difference in precipitation characteristics. However, it is interesting to observe that the older reclaimed site (RSCE) produced sediment at an average rate within the range of the natural sites, while the newly reclaimed site (RNMW) produced sediment at a much higher rate. Scrutiny of the data for individual storms reveals that the plot on hillslope RNMW was producing sediment at a rate similar to the other reclaimed and natural sites toward the end of the period of record. This suggests that hillslopes in this region may achieve a semblance of geomorphic stability in about five years following the application of reclamation practices.

These results differ from those of Lusby and Toy (1976), wherein the reclaimed sites always produced more sediment than the natural sites. According to the memory of the mine company personnel, the surfaces tested in the Lusby and Toy (1976) experiments would have been only a couple of years beyond reclamation at the time.

The runoff (l/m^2) and sediment yield (g/m^2) data from the individual storm events were subjected to simple regression and correlation analyses, with runoff serving as the independent variable (X) and sediment yield serving as the dependent

(Y) variable. Results significant at the 5% level are found for three sites:

NNNE $Y = -0.483 + 1.720X$ (1)

$N = 9$

$r = 0.975$

$Sxy = 1.175$

NNNW $Y = -3.599 + 4.907X$ (2)

$N = 8$

$r = 0.819$

$Sxy = 10.362$

RSCE $Y = -1.414 + 4.344X$ (3)

$N = 8$

$r = 0.987$

$Sxy = 1.692$

The relation between runoff and sediment yield for the plot on hillslope RNMW is not significant. However, examination of the data suggests that extreme values, from storms at the beginning of the record when the surface was barren, likely skew the distribution of sediment yield values. The $\log_{10}$ transformation is employed for this variable with the following result, significant at the 5% level:

RMNW $\log_{10} Y = -0.320 + 0.365X$ (4)

$N = 7$

$r = 0.908$

$Sxy = 0.621$

Sediment Concentration

The sediment concentration can be computed from the volume of runoff and weight of sediment collected. The plots on natural hillslopes, NNNE and NNNW, produced average sediment concentrations of 1,490.1 mg/l and 3,746.3 mg/l respectively, while the plots on reclaimed hillslopes, RSCE and RNMW, produced average sediment concentrations of 3,516.7 mg/l and 26,377.8 mg/l respectively. The same environmental conditions that caused the variabilities in runoff and sediment yield should be responsible for the variabilities in sediment concentration. The average concentration from the older reclaimed site, RSCE, lies within the range from the natural sites; however, that from the newly reclaimed site, RNMW, is much higher. The average from this latter site was heavily weighted by the data for an event in July, 1981, when the concentration approached that of a mudflow.

Particle-Size Distribution of Sediment

The plots on natural hillslopes, NNNE and NNNW, yielded sediments composed of rather similar proportions of sand, silt and clay. However, the plots on the reclaimed hillslopes, RSCE and RNMW, yielded sediments composed principally of clay, with lesser amounts of sand and silt. These sediment data in Table 3 can be compared with the information concerning the particle-size distributions of the soils and surface materials for the natural and reclaimed sites in Table 1. This suggests that the hydrologic processes on hillslopes entrain and transport materials in the silt and clay fractions with the greatest efficiency. The percentages of silt and clay in the sediment are always greater than in the soil or surface material, while the percentage of sand is always less. Here, it seems that particles in the clay fraction are entrained and transported more readily than indicated by the experiments of Wischmeier and Mannering (1969). This might be due to the high sand contents resulting in little soil aggregation.

Conclusion

Runoff and sediment samples from two natural and two reclaimed hillslopes were collected over a 5-year period at the Glenrock Coal company in east-central Wyoming. The average rate of runoff from the reclaimed sites were similar to that from the natural sites, despite differences in hillslope gradient, vegetation cover, and the characteristics of soils and surface materials. These data suggest that hillslope aspect influences runoff generation because the westerly-facing hillslopes produced more runoff than their easterly-facing counterparts.

The older reclaimed hillslope yielded sediment at an average rate within the range of the natural hillslopes, while the newly reclaimed hillslope yielded sediment at a much higher average rate. However, toward the end of the period of record, the rate of sediment yield from this surface appears to be similar to that of the other reclaimed surface and the two natural surfaces. If so, then it seems that reclamation practice and subsequent natural adjustments are capable of recreating a semblance of geomorphic stability in about five years at this study area.

Likewise, the average sediment concentration for the older reclaimed hillslope is within the range for the natural hillslopes, while that for the newly reclaimed hillslope is substantially higher. And again, toward the end of the period of record, the sediment concentration from this surface appears to be similar to that of the other reclaimed surface and the two natural surfaces. This, too, likely reflects the development of vegetation cover at this site through time.

The sediment derived from the natural hillslopes contains roughly the same proportion of sand, silt and clay, while that from the reclaimed hillslopes contains mostly clay. The percentages of silt and clay in the sediment always exceeds the percentages in the soils and surface materials from which they were derived. This suggests that hydrologic processes are selective with regard to the soil separates entrained and transported. At this locale, it seems that the clay fraction is more readily eroded than other authors have suggested. This may be due to the high sand content resulting in minimal aggregation.

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A COMBINATION OF TECHNIQUES FOR RECONSTRUCTION OF EPHEMERAL STREAM CHANNELS IN WYOMING[1]

by

Steve McIntosh[2]

Abstract. A combination of Manning's and geomorphic designs provides a channel construction method which satisfies the full set of requirements for bond release that neither design alone can guarantee. The essence of bond release requirements is a stable valley containing a meandering low-flow channel. Manning's design provides the best assurance of a stable valley. Theoretically a sinuous channel will form within Manning's valley. However unavoidable slope variations in the valley floor will delay or prevent evolution of the meandering channel. To assure formation of a sinuous channel within the 10 year bond period, geomorphic design methods can be used. Premine geomorphic inspections are studied in order to determine the slope and shape of the channel which reclamation authorities consider ideal. This prototype course is superimposed onto the floor of a Manning's valley. Alternating wedge-shaped bars are then installed in the valley to guide low flows along the desired sinuous course. Bars are constructed at a height which does not interfere with valley floods. Using this approach, regulatory mandates for hydrologic reclamation are satisfied assuring achievement of the ultimate industry goal of bond release.

Additional Key Words: geomorphic sizing techniques, meander bars, alternate bar spacing, quasi-equilibrium.

Introduction

Unless stream-channel reclamation methods can begin to address regulatory requirements, mining companies stand to lose a significant amount of bond capital. Too much erosion has occurred on sites where conventional stream-sizing techniques have been used. A new channel reconstruction program is demanded. Manning's design formula has proven the most workable reconstruction format in the past. However, the design has not proven capable of providing answers to all the requirements made of reclaimed channels.

In the mining industry, the success of any reclamation design is measured in terms of its ability to insure permit approval and guarantee a return of bond monies. Manning's model has provided both positive and negative aspects to our reclamation program. Positive features include inexpensive construction, proof of flood capabilities, and channel width measurements which are ideal for formation of a sinuous channel. Negative aspects are an inability to control erosive flows and a lack of visual appeal. The positive elements of

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Manning's equation meet the first objective of a reclamation program by providing assurance of permit approval. The negative aspects can result in a failure to achieve the second goal of bond release. The positive elements of Manning's must not be sacrificed in the formulation of a new design approach.

Goals and Constraints

Mine land reclamation in Wyoming is regulated by the Wyoming State Department of Environmental Quality (DEQ). This agency sets standards for permitting and bond release. As suggested by the DEQ, native materials should be used in the construction of permanent drainages. The reclaimed channels must look and act like the premine courses. The reconstructed channels must also have the theoretical ability to withstand the 100-year, 6-hour flood event. Industry goals are simply to attain permission to mine and to achieve bond release at the minimum possible cost.

Financially, the mining industry considers the ideal reclamation program one which does not require a slowdown or interruption of the processes necessary for ore removal. In this scenario, backfilling and topsoiling are the unavoidable phases of mining during which the ideal reclamation program would take place. In the bentonite-mine region of northeastern Wyoming the smallest piece of construction equipment is a scraper with a 31 cubic yard capacity. At Baroid this means that, during maximum production, each drainage will be constructed by a fleet of scrapers moving soil and spoil at the rate of approximately 70,000 cubic yards of material per hour.

Channel restoration and elaborate engineering designs provide the ideal answer to permit requirements, yet neither approach is feasible. Restoration of any drastically disturbed area has long been recognized as impossible. Both restoration and complex mathematical models require fabrication of myriad channel details. Construction equipment is too large and time is too limited to allow institution of the detail demanded by these approaches.

Though complex engineering design formulas have proven impractical, the information required by Manning's equation is relatively easy to supply, and the resulting blueprints low-cost and simple to implement. Industry demands are met because of operational feasibility. However the unmodified design fails to address the entire set of regulatory goals established for full bond release. Manning's channels provide proof of flood capabilities but, as constructed, they are not appropriate in appearance. The designed flood courses are normally straight, flat-bottomed chutes. Frequently, the meandering channel desired by regulators will not evolve within a Manning's channel within the 10-year bond period.

Discussion

Manning's Equation

Manning's equation (1) defines the maximum permissible flow velocity in terms of channel design parameters:

$$Vp = 1.49/n \times R^{2/3} \times S^{1/2} \qquad (1)$$

where:

Vp = Maximum Permissible Velocity
R = Hydraulic Radius
S = Water Surface Slope
n = Manning's Roughness Coefficient

The premise of Manning's equation is that, if all other factors are held constant, erosion will be decreased if channels are made wide and shallow. Manning's channels are normally trapezoidal in cross section with side slopes at a maximum of about 3h:1v (Figure 1).

Per regulatory requirements, channels are sized for the 100-year, 6-hour event (WDEQ 1980, 1986). Detailed knowledge of the disturbed soil and spoil is not necessarily demanded by Manning's equation. No attempt need be made to accurately characterize the final material used to construct the channel. Rather, the most erosive mixture of soil and overburden which can result from mining is used in Manning's equation. Dimensions calculated using this hypothetical "worst case" material describe the channel most often considered the safest and the most acceptable flood course by regulatory authorities. Consequently, wide Manning's channels are central to the topic program.

Channels designed according to DEQ guidelines are equal in width to the native flood plain. Because of the similarity in appearance, the dimensions for Manning's 100-year, 6-hour course will be termed a valley or flood plain. The wide, shallow course calculated for the 100-year event is consistent with the reasoning behind Manning's sizing technique. Theoretically, the dimensions are meant to describe a course which will allow a meandering channel to develop because it is so wide. And in most cases Manning's valley will promote formation of a sinuous channel. But frequently the time needed for establishment of a meandering channel is too great. A sinuous channel often fails to develop within the ten year bond period. This is largely attributable to irregularities in the bed of the rebuilt valley.

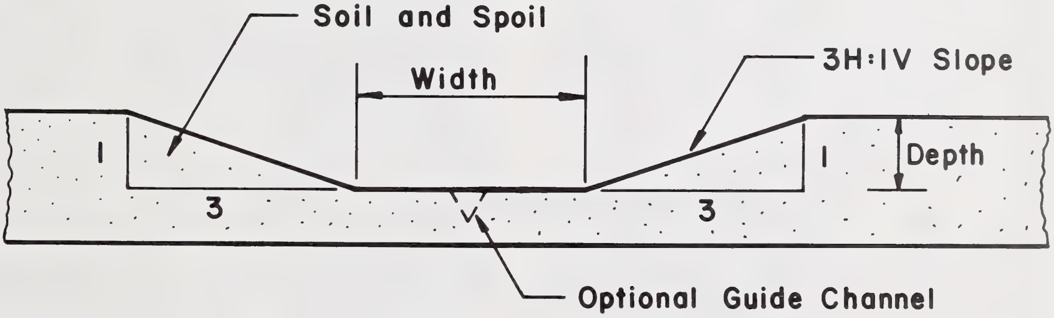

Figure 1. Trapezoidal cross-section of typical Manning's channel. Optional V-ditch guide channel in center of channel.

Design Problems. The most significant shortcoming to Manning's design is the inability of the constructed channels to compensate for slope inconsistencies. Consequently, an unacceptable amount of erosion can occur. The obvious solution is to build uniform channel surfaces. However experience has shown that grade variability is an unavoidable consequence of construction.

When maximum quantities of soil and overburden are being moved, mine equipment is incapable of cutting a consistent channel slope. Lowering the rate of material movement in order to improve channel construction raises production costs while doing little to smooth bed slope inconsistencies.

Inevitably, the final channel floor contains many ridges, furrows and holes which are not part of the initial blueprints. The settling of soil and spoil after placement exacerbates slope variability. Thus unplanned slumps and ridges, not Manning's design slope, often prove to be the major determinant of channel direction. Frequently the pattern and direction of this altered flow is unacceptably erosive.

Several attempts have been made to modify Manning's channels in an effort to produce more natural looking, non-erosive channels. One approach involves cutting the desired low-flow course in the bed of the rebuilt flood plain. These guide channels are commonly narrow V-shaped ditches (Figure 1). Without exception, narrow guide channels have proven to be excessively erosive. A positive aspect of Manning's design is being compromised in an attempt to remedy a negative component. The V-ditch, which is built in order to improve appearance, promotes gullying rather than introducing sinuosity. Low-flow water is denied access to the valley width that is so crucial to the effectiveness of Manning's design. Additionally, the unmodified channels remain unequipped to control erosive flows. Quick adjustment to a sinuous course must be guaranteed. Because bed-slope inconsistencies are unavoidable, grade-control features must be constructed within the Manning's valley.

Geomorphic Design Approach

According to regulatory guidelines, permanent channel features must be made with native materials. Erosion control features built with soil and/or overburden will meet the legal requirements for building materials and can be installed using the mine equipment available. Properly designed, soil bars can be built without compromising peak mine production. However soil bars used in the area in the past have proven unsuccessful as erosion control devices.

The failure of past soil bars can be blamed on two basic design mistakes: (1) placement of bars within improperly designed valleys and (2) construction of inappropriate bar dimensions. In the past, bars were not designed as part of a comprehensive plan. They were installed in order to change channel direction in a valley system which was unstable at the time of construction. The soil bars presented in this discussion are meant to assure sinuosity in a valley designed for the model channel. The proposed bars are placed in a valley in order to reinforce Manning's design theory.

Meander bars have proven to be an asset only in a stable valley system. Soil bars do not have the structural strength necessary to stabilize a valley which is too narrow or too steep in relation to the volume of water it conveys. Nor can soil bars successfully convert a valley from convex to concave-up (looking upstream), a profile that is considered to be stable. The proper profile shape and slope must be insured in the valley design. Geomorphic relationships can be studied to determine the ideal valley configuration.

Manning's design provides suitable one-dimensional blueprints (plan view and cross section) for valley width and depth. But the design does not describe a stable valley. Stability can only be approached if a concave-up valley profile is part of the construction plan. The slope of the profile is dictated by the zone of disturbance. The gradient of the reclaimed valley must be intermediate between the unaffected reaches above and below the zone of disturbance (Bergstrom 1985). Premine valley sinuosity should be copied. The more closely the sinuosity of the constructed flood plain approaches the premine shape, the more guarantee there is that the rebuilt valley will have a concave-up slope which approximates the premine slope.

Channel. Manning's flood valley will contain the channel. The reclaimed channel slope and shape is most appropriately based upon ideal premine channel reaches (Bergstrom 1985). Since bond release is the ultimate objective of this reclamation program, channel appearance should be based on what the reviewing agency considers ideal. Bond release reviews conducted by the DEQ have revealed the channel form which is considered the standard for bond release.

Third-order stream reaches are commonly deemed stable in those sections where sediment flow exiting the area slightly exceeds that which enters. According to this definition, a slight amount of sediment loss is considered the condition of quasi-equilibrium. In appearance, these areas are characterized by well-grassed channel slopes where the low-flow channel is wider than it is deep. Meander bars are alternately spaced in a regular repeating pattern.

Bar dimensions. The second major reason for the failure of past channel bars is improper bar shape. The length, angle, slope and height of soil bars have not historically been considered important dimensions. Meander bars were installed in order to create a sinuous low-flow channel. If bars were built too tall it was not considered harmful. The common feeling was that the higher the bar, the better it would function. But the three-dimensional shape of the bars has proven as critical as position to the stability of the reclaimed hydrologic system.

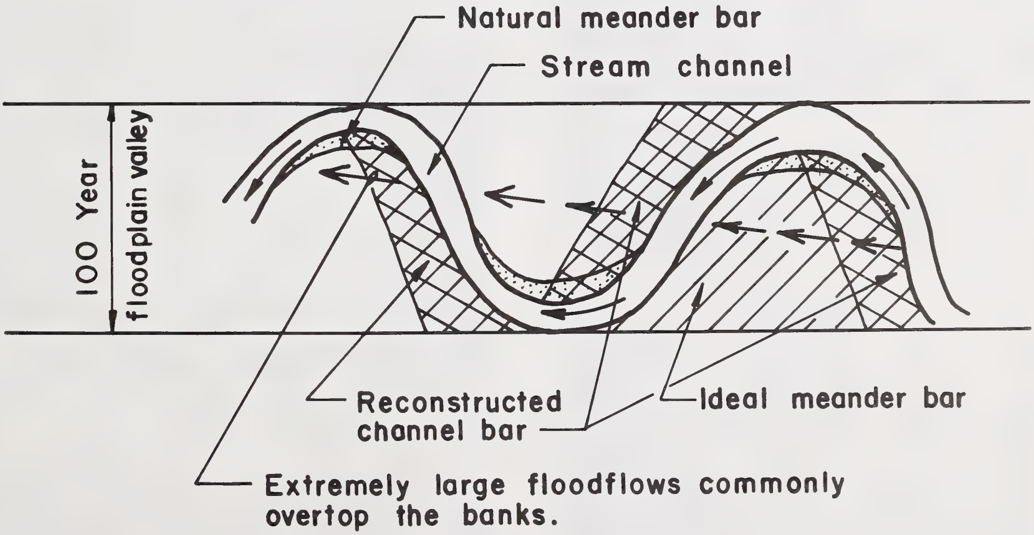
Natural meander bar
Stream channel
100 Year
floodplain valley
Reconstructed channel bar
Ideal meander bar
Extremely large floodflows commonly overtop the banks.

Figure 2. Plan view of ideal stream section. Upstream edge of ideal meander bar is the blueprint for the reconstructed channel bars.

In order to determine channel bar spacing, length and plan-view angle, the ideal premine channel reach is superimposed onto the floor of the valley (Figure 2). This model section is repeated the length of the valley. Irregular channel features which are common in the natural channel are not duplicated. The upstream edge of the ideal meander bar will serve as the blueprint for the proposed channel bars. The origin of each bar is the 100-year valley bank while the distal point represents the inside edge of the 10-year flood channel.

The vertical dimensions of the soil bars are crucial to the stability of the reclaimed stream system. Channel bars are features of the larger valley system and represent an obstruction to major water flows within the Manning's valley. If they are physical barriers, bars can deflect flood flows causing too much erosion on valley walls and on the bars themselves. To maintain state-approved flood capabilities, bars must be shaped in order to account for flood events. The width, depth and direction calculated for each major event must be reflected in the channel bar design.

Flood flows take a more direct route downstream than low flows (Lowham 1987). As flood volume increases (flood event increases), the more direct the route becomes (Figure 3). As theorized here, all events greater than the 10-year flood event will take a more direct down-valley route than is described by the low-flow channel. The smallest flood (10 year) will thus have a slightly sinuous route while the maximum flow (100-year) will take a "straight-line" down-valley route. This means that flood waters will tend to flow over the constructed meander bars. In terms of design, it is essential that flows greater than the 10-year event be allowed to flow freely over each bar.

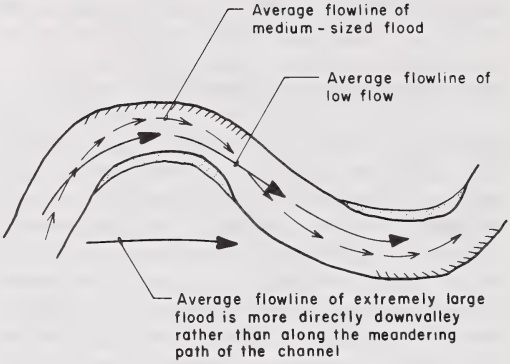
Average flowline of medium - sized flood
Average flowline of low flow
Average flowline of extremely large flood is more directly downvalley rather than along the meandering path of the channel

Figure 3. Average direction of flow of stream at various discharges. For a meandering channel, the average flowline straightens with increasing discharge. (After Lowham 1987).

Study Area

The study area is located on the Redbird 9 mine property in the extreme southeastern corner of Montana, approximately 8.8 miles west of Alzada, Montana. The disturbed channel is an unnamed third-order drainage. The headwater area is steeply dissected, with a maximum elevation of about 3,640 feet and an elevation at the lower end of the disturbance of about 3,530 feet. The mean slope of the premine valley is 3.0 percent. The slope of the low-flow channel averages 1.2 percent. The area of the watershed is about 96 acres.

Topsoil material is highly swelling montmorillonitic clay loam while subsoils are massive, montmorillonitic clays. Spoil material consists of fine, soft marine shales. Both spoil and soil are very saline and extremely sodic which leads to exaggerated subsidence. The high degree of sealing and swelling which characterize these soils results in extremely low permeability and slow water infiltration. Consequently, runoff is very high. The area is largely barren, with drought-tolerant wheat grasses dominating.

Construction of Redbird 9

The Redbird 9 drainage is one of three stream courses built using the outlined construction approach. Construction of the Redbird 9 drainage began in the winter of 1987. Valley width was determined by comparing Manning's 100-year flood plain with the unaffected valley width. For operational purposes the larger of the two widths was used for construction of the valley. By using the greatest valley width, a larger area is available for natural channel adjustments. The large area also facilitates equipment movement should any future reparation work be needed.

The width of the reclaimed valley floor is 80 feet. The channel bars were designed 50 feet long and 20 feet wide. The 10-year flood channel is 30 feet in width. The inside bar angle is about 63 degrees. Each bar is sloped from a height of about 2 feet on the valley wall to 0.3 feet at its distal point. The allowed channel gradient is 1.3 percent. Approximately 40 cubic yards of soil and overburden were used for each bar. This small amount of material was dumped on the valley floor while peak soil movement was maintained. Construction was therefore very inexpensive.

Manning's design was used to determine valley depth and the vertical dimensions of channel bars. Sizes were derived for all flood events from p10 to p100 (valley). The flood courses were then stacked. Stacking is analogous to fitting progressively smaller trays into slightly larger containers. The p10 event is on the valley floor and the largest event (P100) is on top. The outside edge described by this hypothetical stacking represents the design slope of each bar (Figure 4). The final height of the stacked flood channels determined the minimum total valley depth. About one foot of freeboard was added to this height. The bank slopes of the valley are arbitrarily set at a maximum of 3h:1v and a minimum of 5h:1v. These slope percentages appear to be the compromise best suited to allow seeding and provide channel stability. Table 1 summarizes the method used to calculate each hydrologic feature for the Redbird 9 drainage.

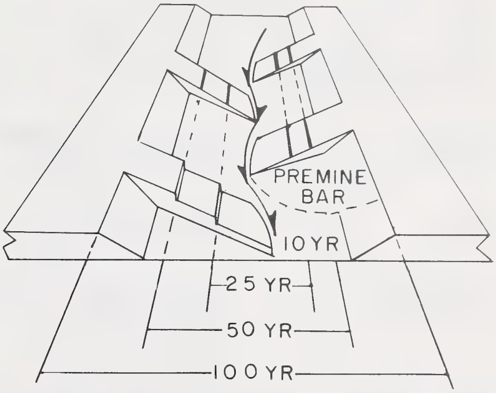

Figure 4. Oblique upstream view of reclaimed valley showing flood event capabilities.

Results

The reconstructed Redbird 9 valley now contains a hydrologic system which resembles the premine state in dimensions and appearance. The reconstructed valley has a concave profile with a slope of about 3 percent. The low-flow channel which has formed on the valley floor has a sinuous course with an average slope of about 1.3 percent. Cross-sectional areas of premine and reclaimed low-flow channels also emphasize channel-measure similarities. The reclaimed low-flow

Table 1. Sizing method used for each valley and channel dimension.

	Valley	**Channel**
Slope	Geomorphic	Geomorphic
Plan View Shape	Geomorphic	Geomorphic
Width	Largest of Geomorphic & Manning's 100-yr. event	Manning's 10-yr. event
Depth	Sum of Manning's 10-100-yr. events	Low-flow channel=free-form*
Features	Side slopes 3:1 max. and 5:1 min.	Alternate Bars: Dimensions: Geomorphic Height/Slope: Manning's
Construction	Cut after overfilling	Dump bar material on valley floor

*'Free-form' implies that unimpeded water flow within the valley is allowed to form the low-flow channel (Lidstone 1982).

channel area (which evolved free-form) averages 2.0 square feet, wheras premine channel area was about 1.8 square feet.

Numerous small runoff events and three bank-full flows have occurred since completion of the drain course. The first major flood occurred two months after construction. Floods were estimated to range between the 5- and 10-year events. During each flood, the ground was frozen or saturated to an estimated depth of six inches. All water flow within the valley occurred before any vegetation was established. The amount of runoff and the susceptibility of the drainage to sediment loss was thus exaggerated (Heede 1974).

Minor flows which contacted a bar eventually made an adjustment from relatively straight to sinuous as low-flow water was guided around the tip of each bar. Major floods coursed over the bars. Thus the bars, rather than bed slope inconsistencies, dictated low-flow channel shape, and a return to premine sinuosity resulted.

The bars interrupted potentially erosive courses in two places. The formation of one gully was due to slope variability caused by equipment limitations. The evolution of the second gully was dictated by snow drifts. Two small ponds formed on the upstream side of the channel bars at these locations. Sediment from subsequent channel flows has completely filled these ponds. System adjustment has occurred to the point of quasi-equilibrium within the valley.

Conclusions

The valid aspects of geomorphic and Manning's channel-sizing theories can be combined in a construction program that is superior to programs designed on the basis of either theory alone. The cornerstone of this approach is a wide valley floor with a concave-up profile. The valley slope should be intermediate between the areas above and below the disturbance. Premine valley sinuosity should be copied from the undisturbed area. This provides assurance that the premine slope gradient and shape will be returned to the reclaimed area.

In design planning, the ideal native channel is superimposed onto the valley floor. Using the sinuosity of this ideal channel reach as the template, soil bars can be installed which counteract valley-slope inconsistencies and assure formation of a stable meandering channel. By constructing each channel bar at a height which compensates for major flood flows, regulatory demands are satisfied; the flaws that can result from using Manning's equation alone are mitigated. Major floods are allowed to flow unencumbered within the valley. Sinuosity is introduced without compromising long-term stability. The end result is a channel which has a concave-up profile with a slope less than the containing valley. Since this slope relationship existed in the premine area, long term stability is assured. The small amount of material needed for each bar made this approach very cost effective. A self-adjusting channel has quickly evolved which satisfies the full set of regulatory and industrial demands. With the assurance of bond release, the ultimate goal of reclamation is achieved.

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AGRICULTURAL CAPABILITY OF SURFACE-MINED LAND IN EAST-CENTRAL ALBERTA[1]

by

S.R. Moran, M.R. Trudell, T.M. Macyk, D.B. Cheel, and Al Howard[2]

Abstract. Between 1979 and 1988, The Plains Hydrology and Reclamation Project (PHRP) studied the impacts of surface coal mining in the plains of Alberta on the agricultural capability and hydrology of reclaimed landscapes. The agricultural capability of reconstructed soil landscapes is generally equivalent to, although less variable than, that of unmined landscapes. Physical and chemical properties of well-drained reconstructed soils are improved through downward leaching of sodium and a decrease in bulk density. Surface wetness and soil salinity result in degradation of capability in small areas of reclaimed sites. The most important hydrologic impact of surface mining is removal of the shallow aquifers that provide the majority of agricultural water supplies. In some areas, replacement water supplies are available from beneath the base of mining. Chemical quality of groundwater in mine spoil is significantly degraded relative to that in pre-existing coal aquifers. Surface mining has essentially no impact on water quality outside of mined areas.

Additional Key Words: Hydrology, reconstructed soils.

Introduction

Between 1979 and 1988, the Plains Hydrology and Reclamation Project (PHRP) investigated interactions of groundwater, soils, and geology and successful reclamation of surface coal mines in the plains of Alberta. The overall goal of PHRP was: (1) to predict the long-term success and the hydrologic impacts of current reclamation practices, and (2) to develop reclamation technology that will allow necessary modification of current practice to assure long-term success and mitigation of deleterious environmental consequences.

The first phase of the study, which was completed in 1984, included characterization and instrumentation of two study sites: the Battle River area, which included Diplomat, Vesta and Paintearth Mines, and the Wabamun area, which included the Highvale and Whitewood Mines (Figure 1). The PHRP study areas are located in the two major coal zones currently being developed in Alberta. The results of the first phase of study led to the focussing of the second phase of the project on: (1) potential salinization of reconstructed soils from shallow groundwater, (2) deterioration of capability for agriculture as a result of differential subsidence, and (3) potential changes in the chemical and physical characteristics of reconstructed soils.

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Acknowledgements

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Agricultural Capability of Reclaimed Landscapes

Maintenance of the capability of reclaimed landscapes for agriculture is one of the most important concerns about surface mining of caol in the plains of Alberta. Dryland agriculture is the dominant land use both before and subsequent to surface mining in most of the plains region of Alberta. Modern reclamation practice in Alberta generally involves grading spoil into long smooth surfaces that are flat or gently sloping. The overall topographic configuration of mined areas is generally slightly elevated relative to adjacent unmined areas because of the swelling or bulking of the replaced spoil. This "bulking factor" causes the reclaimed landscape to be elevated above the surrounding unmined landscape wherever the thickness of the pre-mining overburden is more than about four times that of the removed coal. The topography of the reclaimed area generally reflects a smoothed version of the premining topography with broad low areas where the premining overburden was thinner and locally elevated areas where overburden was thicker. Deep, steep-sided depressions are absent except as final cuts and in areas of older mining adjacent to current operations. From 1.0 to 1.5 m of "subsoil" is placed on the graded spoil using scrapers. About 15 cm of topsoil is then spread over the subsoil.

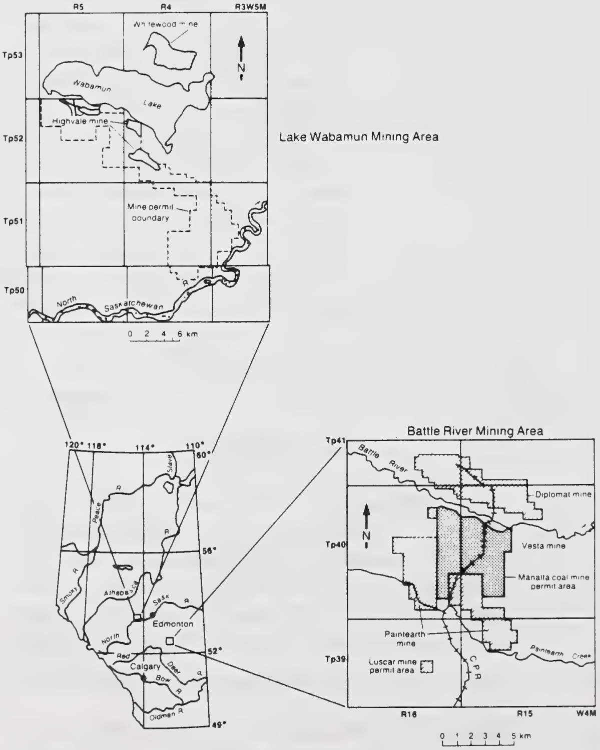

Figure 1. Location of Battle River and Wabamun study areas of the Plains Hydrology and Reclamation Project.

Initial Post-Reclamation Capability Compares Favorably with Capability Prior to Mining

The pre-mining landscape consists of a complex mosaic of soils, which reflect differences in parent material and landscape setting. At the Battle River mining area, for example, 129 individual soil units, representing combinations of as many as five phases of each of 20 soil series in 12 slope classes, were mapped by Macyk and Maclean (1987). Within a limited area, where the same parent material occurs in the same topographic setting, the soil is the same and the physical and chemical properties are quite uniform. Abrupt changes in chemical and physical properties occur within short distances as one passes laterally from one soil to another. These soil units ranged from Capability Class 1, soils that have no significant limitations to agriculture, to Class 6, soils that are not capable of producing perennial forage crops, either naturally or with improvement (Macyk and Maclean, 1987, p. 26-32).

Surface mining alters the scale over which variability in physical and chemical properties of soil occurs within the landscape. As described in the previous paragraph, the premining landscape is characterized by relatively homogeneous conditions on a local scale, but considerable variability over larger areas. Reconstructed soils, on the other hand, are heterogeneous on a local scale, but relatively homogeneous over larger areas (Macyk, 1986, p. 40-41). Mining mixes the soil zone to produce a reconstructed soil mantle of uniform thickness. Much greater variability in chemical and physical properties exists within the reconstructed soil profile and within distances of a few metres than in the unmined landscape. Mixing results in the blurring of the abrupt changes between different soil types that characterized the unmined landscape, resulting in a reconstructed soil mantle that is more uniform in its characteristics over larger areas than is the unmined landscape.

The capability of reconstructed soils for agriculture is generally a reflection of the pre-mining capability. Just as the properties of the reconstructed soil are an average of those of the pre-mining soil, so the capability of reconstructed soils reflect a mix of the pre-mining capability. The agricultural capability of reconstructed landscapes is more uniform than, and is generally not as good as the best nor as poor as the lowest, capability in the pre-mining landscape.

Once the reclaimed site begins to resaturate, water moving on and beneath the soil surface initiates physical and chemical changes that alter the initial capability of the landscape to support agricultural operations. Some of these changes improve the capability, whereas others result in degradation of the capability.

Leaching of Salts Improves The Capability of Reconstructed Soils

The salinity and sodium content of reconstructed soils in well drained sites has been observed to decrease in upland sites studied in the Battle River area between 1984 and 1987 (Moran and others, 1987). This trend was observed in the topsoil at seven of nine locations. The pattern was somewhat more complex in the subsoil, with salinity and sodium concentration decreasing at some depths and increasing at others. The overall pattern is consistent with downward flushing of salts with no evidence that sodium is moving upward from the spoil into the subsoil. Moran and others (1987) concluded that the capability of the reclaimed landscape is improving over time.

Decreasing Density of Reconstructed Soils Improves Capability of Reclaimed Landscapes

Discrete layers of more densely compacted material, which are formed by dozers during grading and scrapers during placement of subsoil and soil, form barriers to infiltrating water and to root penetration. Where these compacted layers or pans persist for extended periods they can significantly decrease the capability of the post-mining landscape. In some areas of the United States, compaction is seen as a major problem for reclamation (Smout, 1987, p. 124-125; McCormack, 1987, p. 23-25; Jansen and Hooks, 1988). Our studies indicate that density is progressively decreasing over time at most sites, which is interpreted to reflect frost action and increasing root penetration by forage crops (Moran and others, 1987). On this basis we conclude that the physical characteristics of reconstructed soils, and therefore the capability, are improving with time.

Differential Subsidence Decreases Capability of Reclaimed Landscapes

Differential subsidence forms depressions that are aligned between the original spoil ridges and appears to be an inevitable consequence of dragline mining (Dusseault, and others, 1985). Newly placed and graded cast overburden, which is considerably less dense than the pre-mining overburden, has a loose structure with an initial secondary porosity of about 25% of the total volume. As water comes into contact with the spoil material, the structure of individual fragments collapses and the spoil quickly loses strength (Dusseault, and others, 1988). Through this process, the entire spoil mass compacts, resulting in subsidence of the land surface (Dusseault, and others, 1985). The majority of the subsidence occurs in the capillary fringe above the rising water table as the spoil resaturates. In addition to area-wide subsidence, which results in general lowering of the land surface, differential subsidence results in formation of numerous oval depressions about 10 m by 20 m and as much as 0.5 m deep. These depressions, which typically occupy from five to ten percent of the reclaimed surface, increase infiltration and accelerate differential subsidence by ponding water during spring melt and heavy summer rain storms.

Ephemeral Ponding Decreases Capability of Reclaimed Landscapes

Ephemeral ponding of water in depressions that form by differential subsidence of spoil decreases capability of a reclaimed landscape for agriculture in two ways. (1) Ponding in the spring disrupts seeding, and during the summer it drowns crops. The ponding produced by spoil subsidence differs from the ponding that characterizes adjacent unmined landscapes in the number, size, and orientation of the ponded depressions. The reclaimed landscape contains numerous small depressions that are distributed in parallel lines across the entire quarter section, whereas the unmined undulating to rolling glacial terrain generally contains a small number of larger depressions per quarter. As a result, ephemeral ponding on reclaimed surfaces potentially results in greater disruption of field patterns, and in wet years, makes farming operations less efficient than on unmined land. (2) Evaporation from the saturated soil around perched ponds in reclaimed landscapes has the potential to produce sodic, saline soils. Hydraulic conductivity of sodic, bedrock-derived spoil is at least two orders of magnitude lower than that of the drift-derived subsoil. As a result, water ponded in subsidence depressions is perched above the permanent water table in the spoil (Figure 2). Evaporation from the saturated soil surface and transporation from plants around the edge of these depressions induces flow outward from the pond and upward from the upper surface of the spoil. Salt and sodium levels in the soil surrounding these depressions are expected to increase over time to levels that are detrimental to vegetation so that capability of these areas is permanently decreased.

Ponding in subsidence depressions can be minimized through modifications of materials placement and grading within existing operations. By grading as much of the reclaimed landscape as feasible into open slopes with integrated drainage, ponding can be minimized. Pauls and others (in prep) report that slopes in the range of 1.5 to 3% along the long axis of these depressions are sufficient to drain about 90% of the water that is ponded on existing reclaimed surfaces.

Salinization Degrades Capability of Reclaimed Landscape in Poorly Drained Lowland Sites

Soil salinity has been observed to form within a few years in lowland settings in reclaimed landscapes, where extensive ponding of surface water develops. This type of setting occurs where thin overburden results in the reclaimed surface being at or below the premining grade. Deep depressions formed by final cuts in these settings become the site of permanent ponds, which result in rapid resaturation of the spoil. Groundwater levels rise to the vicinity of the land surface over extensive areas within one or two decades. Soil salinity develops through evaporation where the water table is within one to two metres of the surface. Salts migrate both outward from the spoil beneath the ponds and downward from adjacent upland areas (Moran and others, 1986).

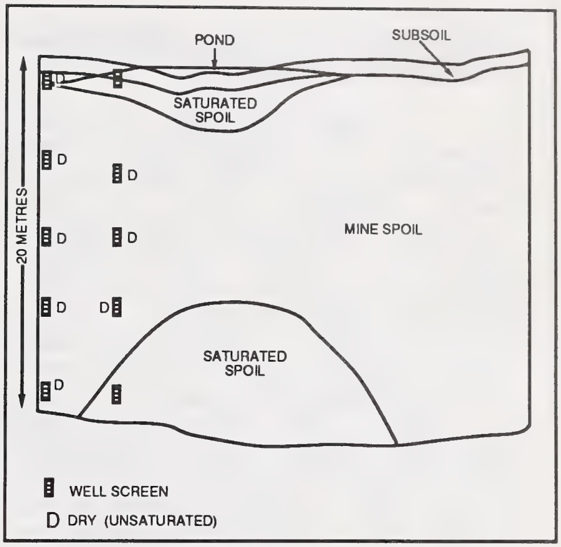

Figure 2. Hydrologic setting of a pond perched above the water table in a subsidence depression at Vesta Mine.

Potential negative effects on agricultural capability in lowland settings can be minimized by appropriate land use. Where attempts are made to grow crops in lowland settings in reclaimed areas, the agricultural capability is expected to be progressively degraded as the salinity becomes worse. Optimum productivity of lowland settings can be maintained, however, by using these areas for forage or pasture.

Surface Mining Lowers Agricultural Water Supply Capability

In areas underlain by surface mineable coal, agricultural water supplies are routinely obtained from wells completed above the coal. Surface mining removes these shallow aquifers. In some areas, replacement water supplies will be available from aquifers beneath the base of disturbance. Although the chemistry of groundwater in mine spoil is significantly degraded relative to that in the pre-existing coal aquifers, surface mining should have essentially no deleterious effects on the water quality outside of the mined areas. Evidence suggests that spoil-derived groundwater will not discharge into surface streams at a sufficiently rapid rate to sensibly alter the water chemistry. Evidence for migration of spoil-derived groundwater into unmined aquifers has been observed only in a single isolated case, where a relatively rare combination of overburden stratigraphy and topographic configuration of spoil existed.

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GEOCHEMICAL RELATIONSHIPS BETWEEN SURFACE MINE SPOILS, SPOIL GROUNDWATERS, AND ADJACENT MINE LAKES[1]

by

Jeffrey P. Schubert[2]

Abstract. Surveys of pre-1975 mine lakes have shown that 90-95% of the lakes are neutral to alkaline (i.e., pH > 6.0). Some lakes, however, may be quite acidic and contain relatively high concentrations of sulfate, iron, aluminum, and other trace metals. Presumably, there are some types of geolog-ical, geochemical, and hydrological data that would be collected prior to mining that might allow us to predict potential water quality problems in advance. Twenty-one mine lakes in the eastern and central U.S. were visited, spoil samples were collected from drillholes around each lake, and water samples were collected from the lakes as well as the drillholes. Many other mining, reclamation, and hydrologic data have been collected. The lake pH values ranged from 2.5 to 8.3. Alkalinity is essentially 0 below a pH of 6.0. Acidity increases greatly with decreasing pH, as does sulfate, iron, manganese, and aluminum. The same general relationships were found true for groundwater in spoil materials. However, groundwaters generally had much higher concentrations than did lake waters at equivalent pH values. The pH (1:1 paste) of the spoil materials ranged from 3.3 to 8.5. The neutralization potentials of individual samples were generally higher when the paste pH values were high. Conversely, the total sulfur values were higher when the paste pH values were low. Correlation analysis between the spoil chemical variables and lake water variables (averaged for each lake) showed several significant relationships. Acidity correlated with many other lake water variables. Our study found a moderately good relationship between net neutralization potential and lake water acidity.

Additional Key Words: water quality, trace metals.

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[1] Paper presented at the conference Reclamation, A Global Perspective, held in Calgary, Alberta, Canada, August 27-31, 1989.

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VEGETATED WATERWAY LININGS REINFORCED WITH GEOMATRIX MATTING -DESIGN METHODOLOGY AND PERFORMANCE-[1]

by

George I. Dodson[2]

Abstract. Design of vegetative erosion control linings for waterways has become an emergent and frequent engineering practice over the past decade. To assess and support performance consistency, several independent field and flume studies are featured, deriving correlations strongly suggestive of a maximum shear restraint performance criteria. A comprehensive baseline design methodology is also proposed to further enhance consistent performance over a range of design and installation variables.

Additional Key Words: Enkamat, linear flow velocity, tractive force, Manning equation, intermittent flow, geotextile, sod, growth curing.

Introduction

Over the past decade several independent studies have been conducted to quantify the design requirements and performance of vegetated waterways permanently reinforced with synthetic geomatrix linings. The empirical results derived from these studies correlate strongly, suggesting defined application parameters for the subject lining category. A standard design methodology is therefore proposed to further quantify and enhance performance of geomatrix reinforcement installations.

Previous Research

The use of permanent synthetic materials for erosion control and vegetation reinforcement originated in the late 1960's. At that time Dutch Akzo engineers began exploring end uses for a unique three-dimensional nylon matrix they had developed. The concept was later formalized. Geomatrix matting vegetation reinforcement products soon became available, initially under the Enkamat trade name.

During 1979 two independent groups studied the reinforcement concept in field and flume trials. A government group, The Pennsylvania Department of Transportation, installed, monitored, and evaluated a roadside diversion channel having a steep flow line slope of 22.5

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percent. Their study concluded that geomatrix reinforced vegetation could endure flow velocities up to at least 20 linear feet per second, at greater than 7.5 pounds per square foot tractive force[3], three times the capability of typical unreinforced grass (Hoffman and Adamsky, 1982).

Also during 1979, Western Canada Hydraulics Laboratories of British Columbia conducted flume tests to determine a maximum permissible shear stress value for channelways lined with Bermuda sod reinforced by geomatrix matting. Their results indicated that the system would consistently endure nominally 8.5 pounds per square foot of shear stress over a two hour flow duration (WCHL, 1979). Seven years later similar results were obtained from an exhaustive field evaluation in Great Britain sponsored by the Construction Industry Research and Information Association. They determined an 8.9 pounds per square foot shear resistance over a one hour flow duration (Hewlett et al., 1987).

All three of the studies occurred in temperate climates with adequate precipitation. To date the only comprehensive evaluation conducted in an arid environment is a 1985 Simons and Li effort in Colorado sponsored by the US Federal Highway Administration and US Department of Agriculture Forest Service. The Simons and Li vegetated flume trials evaluated a lightweight geomatrix reinforcement with sparse vegetation development. Their results indicated an ultimate shear capability of 6.9 pounds per square foot (Chen and Anderson, 1986). Given the conditions of the Colorado study, the results correlate strongly with performance expectations derived from the other three evaluations.

Tractive Force Design Criteria

In practice, designs of permanently reinforced vegetated erosion linings have become reasonably predictive over the past several years as civil engineers and landscape architects have gained experience with the lining concept. A majority of these professionals will typically base their vegetative lining selections on a velocity criteria as derived from Manning's equation. Whereas this practice appears adequate, it does not provide the additional degree of design accuracy necessary for selective engineered usage of erosion control materials, except on a intuitive and qualitative basis.

For example, the design of a vegetated spillway in Columbia, South Carolina required a lining reinforcement that could withstand a linear velocity of 14.7 feet per second, a discharge up to 12,100 cubic feet per second, and a flow depth of up to 10 feet. Intuitively the lining of choice would be a heavyweight geomatrix material. However, given that the channel slope is extremely shallow, approaching 0.5 percent, the maximum design shear stress developed on the lining would be only 3.1 pounds per square foot.

Due to the additional shear stress analysis, permanent reinforcement requirements were found to be less than expected, so a lightweight geomatrix was specified and installed. Consequently the project exhibited proper value engineering. Also, the client had the satisfaction of a quantified and prudent design safety factor, which would have been unavailable if velocity had been the only design criteria.

Velocity, however, has evolved in practice as a design surrogate for tractive flow forces acting on the

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(3) 1 $LB/FT^2 = 4.88 KG/M^2$

channel lining. The criteria is severly limited because velocity is only approximately constant over a narrow range of channel shape (R) and roughness (n) (Chen and Cotton, 1988). It is, furthermore, the force developed by the flow, not the flow velocity itself, that determines erosion lining failure and success.

The tractive forces acting on the lining will typically create a discrete level of shear stress which defines a constant design parameter virtually independent of randomness due to channel shape and roughness. Furthermore, the higher stresses developed in channel bends can be quantified by simplified shear stress calculations, providing a higher level of design confidence than otherwise possible.

The formula for maximum shear stress is:

$$\tau_C = \gamma DS \qquad (1)$$

In practice, flow depth (D, feet or meters) and channel slope (S, percent, e.g., .1 equals 10 percent) are directly quantifiable. Also the unit weight of water is defined for most conditions, (γ, 62.4 pounds per cubic foot or 863.7 kilograms per cubic meter). In contrast, channel roughness is a more arbitrary range value determination, varying with grass development, flow regime, and slope steepness (Hewlett et. al., 1987).

Since maximum shear stress is virtually constant over a channel section, it provides an umbrella lining criteria for a wide range of flow conditions, and solely allows for the development of implicit design safety factors over that range. The critical shear stress criteria furthermore readily facilitates simplified comparisons of lining performance from site to site.

The critical shear stress determinations are meant to be used in tandem with velocity calculations for pre-screening of channel lining designs. Manning's equation will undoubtedly remain as a primary hydraulic design tool. However, as the FHWA, and everyday practice have determined, a focused simplified screening criteria for channel lining selection (such as maximum shear stress) is necessary to continually ensure properly engineered design (Chen and Cotton, 1988).

Design Methodology

Prescreening

From results of the independent evaluations previously mentioned and other field experience, the conservative permissible shear stress values for permanent geomatrix reinforced vegetated linings e.g., Enkamats, are 6.0 pounds per square foot for lightweight geomatrix reinforcement and 8.0 for heavier matting reinforcement. Comparatively, riprap with a mean diameter of two feet also has a permissible shear stress of 8.0 pounds per square foot, and the maximum shear capability of class A unreinforced vegetative stands is only 3.7 pounds per square foot (Chen and Cotton, 1988). For class A vegetation, typical design values under sustained flow would be 3.0 or less pounds per square foot.

Thus over the flow-induced shear stress range of 3.0 to 8.0 pounds per square foot (14.7 to 39.1 kilograms per square meter), permanent geomatrix reinforced linings have reasonable design applicability. Additional design considerations would be local climate and soil type.

Performance Factors

Flow Frequency. Vegetative linings are appropriate for conditions of intermittent flow. In a channel flow line, vegetation will not become established when the zone is continually wet for long periods. On some occasions, therefore, the necessity arises to design a non-vegetated solution for the flow line in tandem with reinforced vegetation on the side slopes.

Flow Duration. Flow duration influences the shear restraint capabilities of geomatrix reinforced and other vegetated lining systems. As example, the parameter of 8.0 pounds per square foot for heavyweight geomatrix lining systems is a conservative figure based on a two hour flow duration. Between two and ten hours duration the system will loose up to eleven percent of design strength, and up to an additional thirteen percent at fifty hours of flow (Hewlett et. al., 1987). The trend of strength versus flow duration is similar among both reinforced and unreinforced vegetated linings, with the reinforced categories retaining much higher performance capabilities over all flow durations.

Soil Preparation. The compactive effort on a soil can raise site shear strength by up to .4 pounds per square foot (Chen and Cotton, 1988). In soil media where ultimate compaction and inherent soil cohesion are negligible e.g., dune sands and some mine spoils, soil amendments are available to raise the level of both qualities. Should soil fertility pose a significant barrier to vegetation, ferilizers and mulch amendments may be required.

Geomatrix Underlays. An underlay of biodegradable mulch or of porous geotextile may become necessary. If the climate is semi-arid or arid, a moisture retaining mulch blanket may provide the necessary retention media to facilitate growth. A mulch or geotextile underlay also will provide added durability if the system is developed over highly erodable soils. The geotextile, being permanent, will contribute design strength to the lining, up to an additional 1.0 pound per square foot of shear restraint. Whenever employing a geotextile underlay, the overlaying geomatrix should be filled with fertile, cohesive soil to facilitate plant growth.

Seeding. Local seeding experts are available for consultation through private firms, universities, and government agencies. Since indigenous seed types tend to be best suited for local sites, local experts are the most qualified to comment on seeding. There are, however, two criteria which are vital to the selection of a vegetative cover. Of primary importance the vegetation mix should be able to germinate quickly during the season when the lining is installed. Secondly, the selected vegetation should develop a dense root system capable of extensively knitting with the geomatrix reinforcement matting. Usually the higher the documented maximum shear strength of the selected vegetation, the more appropriate it is for a permanently reinforced system. Where sod is available and cost effective it often provides a more aesthetic alternative to seeding, especially in the early growth curing stage of installation.

Installation. The primary relevant installation variables are grading, laydown, and staking. When the contractor fine grades a site, meaning that he leaves a smooth surface conforming to the local terrain, he facilitates the opportunity to create intimate contact between the geomatrix and soil surfaces, thus preventing undercutting of the system. The subsequent laydown effort is similar to that of placing roof shingles, as the crew unrolls the geomatrix matting from the downstream end up the channel, allowing the geomatrix mat to "shingle" down the flow line of the channel.

During laydown, staking should take place on three foot centers, preferably with triangular wooden stakes. They create local zones of compaction and anchorage. Wooden stakes will also resist frost heave since they tend to swell and lock into adjacent soils when introduced to moisture. Metal staples are not usually recommended because they do not create localized compaction anchorage, and they are highly susceptable to frost heave.

In-Situ Performance

The first six months after installation constitute a period when the system "growth cures," or develops to full strength. The seed germinates and grows while the matting becomes filled with sediment. Overall, a fertile substrate is being developed which enhances further and denser growth.

Upon installation a reinforced vegetative lining provides up to 5.0 pounds per square foot of shear restraint for the lightweight geomatrix, up to 7.0 for the heavyweight. During the growth curing period additional strengths develop with vegetation emergence. Ultimate maximum design strengths of 6.0 and 8.0 respectively result from the synergistic combination of soil, grass, and geomatrix matting. Even higher strengths (an additional 1.0 pound per square foot) are obtainable with a permanent porous geotextile underlay.

As the reinforced system cures and evolves, lining roughness will inherently change. Upon installation the unfilled geomatrix mat has a characteristic surface roughness determined by its dimensional stability and profile height. As the mat fills with sediment to create a viable fertile substrate, roughness begins to decrease. The growth of emergent grasses will cause a gain in surface roughness until the grass blades later become long enough to lay down and create a smooth surface. Over the system design life further minor roughness variations will occur coincident with the growing seasons.

Conclusions

Independent formal studies in North America and Europe conducted over the past decade provide strongly correlative results regarding the design performance of permanent, geomatrix reinforced vegetative linings for waterway erosion control. These findings readily suggest a discrete value design window for this lining category conservatively ranging from 3.0 to 8.0 pounds per square foot of flow-induced shear stress (14.6 to 39.0 kilograms per square meter). Furthermore, proper design and installation of the permanently reinforced vegetative linings has resulted in positive, repeatable performance over a vast range of climatic, soil, vegetative, and flow conditions.

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Herbaceous Revegetation

Session Chairmen: J. Friedlander and E.J. DePuit

PROMISING NATIVE FORBS FOR SEEDING ON MINE SPOILS[1]

by

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Abstract. Twenty nine species of perennial forbs and 2 biennial forbs were directly seeded into coal mine spoil materials at Dickinson, North Dakota to determine which species would be most successful for direct seeding into coal mine spoil. Those which showed exceptionally good emergence and vigorous growth of seedlings in a two year study were: white prairie clover (Petalostemum candidum), wild licorice (Glycyrrhiza lepidota), prairie coneflower (Ratibida columnifera), blazing star (Liatris punctata) and long-leaved milkvetch (Astragalus ceramicus). Species with lesser but acceptable germination only were: white upland aster (Aster ptermicoides), purple coneflower (Echinacea angustifolia), early goldenrod (Solidago missouriensis), green milkvetch (Astragalus striatus), purple prairie-clover (Petalstemum purpureum) and evening star (Metzelia decapetala). Other species tested showed little to no germination and hence difficult to establish by direct seeding into coal mine spoil.

Additional Key Words: forbs, seeding, reclamation, revegetation.

Introduction

Forbs are herbaceous or semi-woody plants such as fringed sage-wort (Artemisia frigida) or winter fat (Eurotia lanata) (Stevens 1963, Thornburg 1982, Wasser 1982). Other herbaceous plants include grasses, sedges and rushes. Forbs are the most numerous group of plants but are seldom dominant and almost always occur in mixtures. They may be perennials, biennials (live two years) or annuals which may be fall or spring annuals i.e., seed germination occur in fall or spring time of the year. Forbs, due to persistant high level of nutrients, are an important part of the diet of wildlife, including big game animals and birds, and livestock. However, they are usually of limited abundance whereby animals need to select for these forbs in order to ingest sufficient amounts to supplement nitrogen and phosphorous need in the diets (Alexander et al. 1983, Peterson 1989).

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Grazing systems are generally focused around the graminoid component of the grassland ecosystem and it is this component that has received the greatest attention by managers and researchers. This has been done with studies which dealt with floristics (Peterson 1989), community descriptions (Hanson and Whitman 1938, Hirsch 1985, Girard et al. 1989), seasonal nutritional composition of grasses and shrubs (Whitman et al. 1951, Jefferies and Rice 1969, Williamson 1979), and phenology of selected range plants (Peterson 1989). Results of these studies show forbs as merely a minor component of the environment and added mainly structure, increased diversity and enhanced aesthetic qualities. Forbs were recognized as indicators of range condition and mesotrophism (Weaver and Albertson 1943). They were also noted to be the first to take great advantage of reduced cover following the great drought of the 1930's (Weaver and Albertson 1944), in other words they were the pioneers to rehabitate the site during early successional stages.

The forb component and their management remains to be understood and described, even though its importance was recognized 15 years ago (Ferguson and Monsen 1974). This problem continues because we do not know which forbs are most promising and the cultural practices required or the site conditions most conducive to their establishment. Previous studies indicate severe problems with the germination is a major deterant to forb establishment (Blake 1935, Tolstead 1941, McDonough 1969, Sorensen and Holden 1974, Voigt 1977).

The objectives of the study were to (1) determine optimum seed storage and germination environments for 29 species of perennial forbs common in western North Dakota (Hanson and Whitman 1938), (2) determine the germination of these forbs seeded in mine spoil material under actual field conditions, and (3) compare the height growth of plants seeded with those propagated by the use of containerized seedlings.

Procedures

Seed collection on native ranges in western North Dakota began as soon as seed appeared in seed dispersal stage, usually late June for cool season forbs and as late as October for warm season forbs (Table 1). The recognition of forbs as with grasses according to season of growth, ie. cool or warm season, provides extended periods of growth when appropriately mixed to provide balancing of these species (Thornburg 1982, Wasser 1982). This was recognized in the selection of species used in this study (Table 1).

The forb seeds were stored in glass bottles at room temperature during the summer, threshed-out by hand rubbing and hand-screening and returned to the glass bottles. Most seeds threshed relatively clean but some appendages or portions of appendages remained attached. This occurred with yarrow (_Achillea lanulosa_), sagewort wormwood (_Artemisia caudata_), white upland aster (_Aster ptarmicoides_), wild buckwheat (_Eriogonum multiceps_), butterfly weed (_Gaura coccinea_) skeleton weed (_Lygodesmia juncea_) golden aster (_Chrysopsis villosa_), the goldenrods (_Solidago spp_.) and goatsbeard (_Tragopogon dubius_).

Three storage treatments were applied to separate lots of the forb seed. These treatments were (1) dry storage at room temperature, (2) dry-cold storage with seed subjected to normal outdoor winter temperature fluctuations, and (3) wet-cold storage with moisture weekly monitored

Table 1.--List of species collected near Dickinson, North Dakota used in experiment on forb establishment and season of growth.

Scientific name	Season of growth*
Achillea lanulosa	C
Artemisia caudata	W
Aster ptarmicoides	W
Astragalus ceramicus	C
Astragalus flexuosus	C
Astragalus striatus	C-W
Campanula rotundifolia	C-W
Chrysopsis villosa	W
Echinacea angustifolia	C
Eriogonum multiceps	C
Gaillardia aristata	C-W
Gaura coccinea	C-W
Glycyrrhiza lepidota	C
Helianthus rigidus	W
Liatris punctata	W
Linum lesisii	C
Lygodesmia juncea	C-W
Mentzelia decapetala	W
Penstemon angustifolius	C
Petalostemum candidum	W
Petalostemum purpureum	W
Psoralea esculenta	C
Ratibida columnifera	W
Solidago missouriensis	W
Solidago mollis	W
Solidago rigida	W
Sphaeralcea coccinea	C
Suaeda fruticosa	W
Tragopogon dubius	C
Vicia americana	C

* C=Cool Season, W=Warm Season

and added to keep seed maintained in moist conditions at approximately 4 C in a refrigerator. The seed storage period began on December 1.

All germination trials were conducted using a Seedburo Model 3516 germinator maintained at a temperature of 21 °C. Triplicate lots of 25 seeds each, tested for viability using the tetrazolium test (Ferguson and Monsen 1974) were germinated on moist chromatography paper in square petri dishes. Germination trials of room temperature and cold-dry stored seed were begun on the 9th of January and subsequent trials of each species thus treated were begun on the approximate same day of the month each month thereafter through May. Germination trials of the wet-cold treated seed were begun on January 16 and were continued for the rest of the 5-month period beginning on the approximate same day of each month. The germination period allowed for each trial was 60 days, after which the ungerminated seed of each trial lot remaining in the petri dishes was discarded. Germination was considered to have taken place when the radicle appeared, and the germinated seeds were removed from the petri dishes at that time.

Germination of pretreated forb seeds was also tested on spoil piles, constructed from raw coal spoil material hauled to the Dickinson Experiment Station from North American Coal Corporation's Indianhead Mine near Zap, North Dakota. The sandy clay loam texture and void of organic matter material was from a depth of 9-12 meters (30-40 feet). The spoil material was spread to a depth of 30 cm (14 inches). The surface was rototilled before seeding.

Each spoil pile was divided into plots 1.2 x 1.2 m (4 x 4 feet) in size. The seedings were made in two replications per treatment from each species. Seed was broadcast by hand and raked. Application rate was considered to be heavy when compared to seeds of similar size of tested seeding rates (Thornburg 1982). Plots were seeded the first week of June.

Container-grown seedlings used for height growth rate comparison were germinated starting the previous December and transplanted into the spoil the first week of June. After the completion of the transplanting and seeding of the plots, all plots were watered with a fine-spray as needed to keep the surface damp.

Results and Discussion

While the results of this trial show some inconsistencies, all species showed some germination under all treatments. Cluster analyses using ISODATA showed some species benefited by cold treatment and showed increased germination under this treatment than when stored at room temperature. Included in this group were Chrysopsis villosa, Ratibida colummnifera, Solidago missouriensis, S. mollis, S. rigida, Aster ptarmicoides and Mentzelia decapetala (Table 2).

A few species had less germination under the dry cold treatment than under room temperature storage. Included in this group were Echinacea angustifolia, Gaillardia aristata, Glycyrrhiza lepidota, Linum lewisii, and Suaeda fruticosa.

The wet-cold storage treatment was especially beneficial to Mentzelia decapetala and Penstemon angustifolus. Mentzelia continued to increase in percent germination throughout the period of wet-cold storage with May trial showing 92 percent germination, the highest germination shown by any perennial species in the trial. Penstemon showed satisfactory germination only under the wet-cold treatment, reaching 76 percent in the February test, but declining thereafter.

Table 2.--Percent germination of forb seeds collected in the summer, stored under three different conditions and tested in the winter and spring.[1]

Species	Room temp. storage					Dry cold storage					Wet cold storage				
	Jan.	Feb.	Mar.	Apr.	May	Jan.	Feb.	Mar.	Apr.	May	Jan.	Feb.	Mar.	Apr.	May
Glycyrrhiza lepidota	65	80	75	77	79	57	71	61	56	60	77	52	69	75	55
Tragopogon dubius	56	57	72	80	93	51	83	87	89	31	28	4	19	93	49
Liatris punctata	51	63	16	71	67	68	35	57	69	72	36	65	41	73	64
Solidago rigida	4	21	24	15	32	41	31	44	48	21	41	51	55	25	17
Solidago mollis	17	52	60	16	32	33	55	44	36	29	9	31	23	3	12
Aster ptarmicoides	9	20	15	36	35	11	31	28	39	29	5	65	29	45	32
Chrysopsis villosa	20	25	32	17	16	17	37	24	22	29	32	36	12	33	40
Solidago missouriensis	23	13	47	24	15	40	45	32	29	23	64	25	5	20	7
Linum lesisii	16	23	36	33	79	4	25	16	13	43	14	25	1	41	20
Mentzelia decapetala	0	1	12	4	1	7	1	1	4	17	29	81	53	83	92
Petalostemum candidum	13	33	25	12	11	36	23	21	23	8	36	23	16	19	25
Artemisia caudata	16	40	16	15	8	25	15	19	20	12	15	16	36	11	24
Ratibida columnifera	11	20	20	0	16	29	25	13	17	17	1	17	16	5	9
Gaillardia aristata	23	19	24	11	15	7	12	5	7	8	5	16	16	13	23
Astragalus striatus	16	21	7	21	11	8	7	12	13	12	11	16	35	12	13
Petalostemum purpureum	12	21	29	1	5	12	3	13	11	4	11	11	4	8	8
Echinacea angustifolia	11	15	13	27	12	9	5	12	7	1	5	9	13	0	7
Vicia americana	5	20	16	7	3	3	11	5	11	4	9	21	15	11	4
Penstemon angustifolius	0	3	0	0	3	1	0	3	0	5	19	76	8	12	0
Suaeda fruticosa	0	7	11	23	5	3	0	1	8	4	0	20	24	12	8
Thermopsis rhombifolia	9	21	5	0	8	7	8	3	5	7	20	8	7	11	4
Astragalus flexuosus	5	15	4	8	0	0	3	1	8	4	7	5	8	3	3
Astragalus ceramicus	5	3	7	5	0	7	0	0	11	3	5	9	9	3	0
Achillea lanulosa	8	0	3	0	0	3	0	3	4	0	24	0	13	3	0
Campanula rotundifo	4	0	0	28	1	0	0	9	8	0	4	5	8	5	1
Eriogonum multiceps	0	13	3	27	12	3	1	0	1	1	1	2	1	0	3
Lygodesmia juncea	1	4	0	0	0	4	0	0	0	1	5	13	3	0	1
Gaura coccinea	7	1	4	3	0	3	3	5	0	1	4	0	0	0	0
Helianthus rigidus	1	3	3	4	1	1	1	0	0	3	0	12	7	8	4
Sphaeralcea coccinea	4	5	1	1	0	1	1	1	0	0	0	7	3	0	1
Psoralea esculenta	9	-	-	-	-	3	-	-	-	-	5	7	-	-	-

[1] Storage period for all treatments was considered to have begun on Dec. 1. Germination tests began on the 10th of the month indicated and each lot of seeds was observed for 60 days thereafter except for the May trials.

Other species which showed small to moderate benefit from the wet-cold storage treatment included *Aster ptarmicoides*, *Astragalus ceramicus*, *Chrysopsis villosa*, *Helianthus rigidus*, *Lygodesmia juncea*, *Petalostemum candidum* *Suoeda fruticosa*, *Thermopsis rhombifolia*, and *Vicia Americana*. *Achilles lanulosa* apparently benefitted from a short period of cold-wet storage, but prolonged storage under these conditions appeared to be detrimental.

From the results of this germination trial the requirement for a cold treatment before most of the forbs will show satisfactory germination rates seems to be somewhat in doubt. This requirement may be related to previous seasonal growing conditions and the conditions under which the seed matured. In a normal field situation, most forb seed will receive either a dry-cold or a wet-cold treatment during the winter after the seed is produced. Whether this treatment is essential during storage before direct seeding into mine spoil for satisfactory germination now seems somewhat doubtful.

Germination of the 29 forb species direct seeded on the mine spoil took place over a relatively long period of time. Twenty-three species showing some germination and seedling emergence within 120 days, by the end of August (Table 3). Six species that did not germinate under natural mine spoil conditions were: *Penstemon angustifolius*, *Solidago rigida*, *Helianthus rigidus*, *Campanula rotundifolia*, *Suaeda fruticosa* and *Lygodesmia juncea*. The species that showed exceptionally good emergence of seedlings and subsequent vigorous growth included: *Petalostemum candidum*, *Glycyrrhiza lepidota*, *Ratibida columnifera*, *Liatris punctata*, and *Astragalus ceramicus*.

Table 3.--Estimated number of seedlings per square meter produced in one growing season on mine spoil plots seeded June 9 and estimates made in August and listed according to highest number per square meter.

Species	No. seedlings/m^2
Astragalus striatus	356
Petalostemum candidum	335
Mentzelia decapetala	302
Tragopogon dubius	280
Glycyrrhiza lepidota	248
Liatris punctata	204
Astragalus ceramicus	140
Petalostemum purpureum	140
Chrysopsis villosa	97
Linum lewisii	43
Echinacea angustifolia	32
Astragalus flexuosus	21
Solidago mollis	21
Sphaeralcea coccinea	21
Thermopsis rhombifolia	11
Ratibida columnifera	11
Aster ptarmicoides	11
Eriogonum multiceps	11
Achillea lanulosa	T*
Artemisia caudata	T
Solidago missouriensis	T
Gaillardia aristata	T
Gaura coccinea	T
Penstemon angustifolius	0
Solidago rigida	0
Helianthus rigidus	0
Campanula rotundifolia	0
Suaeda fruticosa	0
Lygodesmia juncea	0

*T = Seedlings present but averaging less than 1/m^2.

Fourteen species of the container-grown seedlings were successfully transplanted and height growth measurements on the unheaded stalks were taken (Table 4). These transplants were started from seed in December and transplanted into the spoil in June. All container grown seedlings survived transplanting and grew successfully on the spoil material until heights were measured on August 30 (Table 4). *Solidago rigida*, *Mentzelia*, *Campanula*, *Liatris*, and *Penstemon* remained in the rosette growth form throughout the season. In this form they appeared vigorous and developed well but did not make height growth. Those species which grew the most included the two *Petalostemum* species, *Ratibida*, *Glycyrrhiza*.

Some seedlings and transplants grew more vigorously than others (Table 4). In general the transplants of the species reached greater heights by the end of first growing season than did the plants of the same species grown directly from seed. However, the plants grown directly from seed did remarkably well with four producing flower stalks by August 30 of the first growing season (Table 5). Container-grown seedlings of the same species produced flower stalks of similar heights the first growing season.

Numerous newly emerged seedlings from the previously direct seeded forbs were observed the following June. Seedlings from previous year planted seeds were especially abundant on plots of *Solidago mollis*, *Mentzelia decapetala*, *Thermopsis rhombifolia*, *Helianthus rigidus*, *Penstemon angustifolus*, *Aster ptarmicoides*, and *Echinacea angustifolia*. The inference is that

Table 4.--Average heights of plants, seeded and container-grown transplants in mine spoil material at Dickinson, North Dakota at end of first growing season.

	Average Plant Height (cm)	
Species	Seeded	Container
Suaeda fruticosa	19 ± 1.3[1]	--[3]
Glycyrrhiza lepidota	17 ± 0.4	15 ± 2.4
Astragalus ceramicus	16 ± 3.8	--
Petalostemum candidum	10 ± 2.6	34 ± 1.2
Artemisia caudata	6[2]	--
Mentzelia decapetala	6[2]	9 ± 1.7
Liatris punctata	5 ± 1.9	3 ± 0.8
Echinacea angustifolia	5 ± 0.0	3 ± 0.8
Thermopsis rhombifolia	5 ± 0.0	10 ± 1.7
Astragalus striatus	5[2]	2 ± 0.0
Ratibida columnifera	4 ± 0.6	25 ± 3.9
Aster ptarmicoides	4 ± 0.0	11 ± 0.6
Eriogonum multiceps	2 ± 0.0	--
Solidago rigida	2 ± 0.0	11 ± 1.0
Helianthus rigidus	1	12 ± 4.0
Solidago missouriensis	1	--
Campanula rotundifolia	--	4 ± 1.6
Penstemon angustifolia	--	5 ± 0.9

[1] ± standard error.
[2] ± mean per plot, no replication.
[3] Not included.

Table 5. End of growing season average heights of flower stalks developed on container transplants and on plants seeded on mine spoil material at the Dickinson Station.

	Average flower stalk height (cm)	
Species	Container	Seeded
Petalostemum purpureum	20	25
Petalostemum candidum	24	31
Helianthus rigidus	-	50
Ratibida columnifera	17	29
Thermopsis rhombifolia	25	-

seed will lie dormant for several years and overwintering under natural conditions will promote germination and emergence of seedlings from previously dormant seed. The fall rains and winter conditions on the northern Great Plains would provide a wet-cold treatment.

Summary and Conclusions

Thirty one species of highly valued forbs on the northern Great Plains were selected for evaluations as to their suitability for seeding on coal mine spoils in North Dakota. Two biennials, Artemisia caudata and Tragopogon dubius, were included due to their high visibility and availability of seed to reclamation specialists. All thirty one species showed some germination under all treatments. However, germination of Chrysopsis villosa, Ratibida columnifera, Solidago missouriensis, S. rigida, Aster ptarmicoides, and Mentzelia decapetala was increased when receiving the dry-cold treatment compared to storage at room temperature. The wet-cold storage treatment was beneficial to Mentzelia decapetala and Penstemon angustifolius. Therefore, these species should be fall seeded, or if placed in dry winter storage the proper treatment should be applied for maximizing germination prior to spring seeding. Species tested which had special germination problems requiring further investigation include Achillea lanulosa, Astragalus ceramicus, Astragalus flexuosus, Campanula rotundifolia, Eriogonum multiceps, Gaura coccinea, Lygodesmia juncea, Psoralea esculenta, and Sphaeralcea coccinea. Those perennial forbs which demonstrated exceptional promise for direct seeding in seed mixtures on mine spoils were: Petalostemum candidum, Ratibida columnifera, Glycyrrhiza lepidota, Liatris punctata and Astragalus ceramicus.

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DIVERSITY AND SEASONAL VARIETY IN RECLAIMED NATIVE GRASSLANDS[1]

by

David J. Nilson and Kathie J. Hirsch[2]

Abstract. Production and cover data from a 216 ha reclamation area were collected between 1982 and 1988 for purposes of determining vegetation success and to evaluate establishment and management practices. Nineteen site types were identified where vegetation differed due to seeding date, mulch type, and reconstructed soil characteristics. Diversity and seasonal variety changes over time are discussed for 3 sites relative to an on-site reference area standard. Data show proper seed mixtures, seeding date, glyphosate (Roundup) treatments, and the use of a native hay mulch can effect species composition and contribute to diverse productive reclaimed grasslands.

Additional key words: Native grassland restoration, grassland diversity and seasonal variety.

Introduction

Bond performance standards under SMCRA for native grassland reclamation require mine operators to demonstrate that established stands are diverse, effective and permanent. Also, they must have the same seasonal variety native to the area. These requirements make it necessary to know what establishment and management practices are available and effective to meet these goals.

Monitoring reclaimed grasslands is important in determining diversity and seasonal variety in relation to requirements for final bond release. Trend information should be obtained several years before the end of the liability period in order to prescribe management practices to direct plant community succession. These practices may include prescribed burning, mowing or grazing. However, if species diversity or seasonal variety is deficient in the initial stand, none of these are useful. Interseeding, combined with burning and/or non-selective herbicide (glyphosate) treatments, is effective (Nilson et al. 1985) but this restarts the 10 year liability period because interseeding is not considered a normal conservation practice.

Diversity and seasonal variety characteristics on reclaimed grasslands at the Glenharold Mine have been studied over the past 10 years. Study sites have included reclamation areas where seed mix and seeding date varied, non-selective herbicide treatments were used, or where native hay was used as a mulch. Data have been collected to evaluate both the short term and long term benefits of these practices.

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Information presented in this paper are from a 216 ha (534 ac) grassland area seeded between 1981 and 1983. This area is referred to as the Glenharold Mine (GHM) section 15 grassland reclamation area.

Study Area

The Glenharold Mine is located 88 km (55 miles) northeast of Bismarck, North Dakota in a landform known as the "Missouri Breaks". Native prairie consists of mixed grasses of the wheatgrass-stipa-grama association. Principle soils include mollisols and entisols underlain by sodic montmorillonitic clays which are typical in spoil material. Major range sites are shallow, silty, sandy and thin claypan sites.

Native soils for this area were somewhat atypical of the mine as a whole. Most of the area was dominated by sands and thin sands range sites. Premine soils were of the Lihen and Telfer series' which have loamy fine sand textures. Following topsoil removal, sandy clay and clayey subsoils were selectively stripped down to 25 feet in deposits of brown glacial till. This was done to avoid reconstruction of a droughty soil profile where sandy topsoil is placed over sandy subsoil material. Consequently, the reclamation area has two basic soil profiles with soil characteristics that affect reestablished plant communities. One is the mined disturbance area which had both topsoil and subsoil replaced and the other is the associated disturbance areas which retain their original subsoil soil characteristics.

Major forage species present prior to mining, as recorded from an on-site reference area, were needle-and-thread (Stipa comata), blue grama (Bouteloua gracilis), prairie sandreed (Calamovilfa longifolia), little bluestem (Andropogon scoparius), sand bluestem (Andropogon hallii) and sedges (Carex spp.).

Methods

The section 15 reclamation area was delineated into 19 vegetation site types designated A-V in Table 1. Vegetation differences in these sites were influenced by a number of factors but were due primarily to conditions resulting from different seeding dates between 1981 and 1983. Other factors included whether or not both subsoil and topsoil were replaced or if only topsoil was affected. Also, differences were observed where native hay and slough hay were used as mulch as well as areas where broadcast seeding was used instead of drill seeding.

All sites seeded in 1981 were seeded with the same seed mixture (Table 2). In 1982, alfalfa (Medicago sativa) was seeded instead of sweetclover (Melilotus officinalis) at approximately the same rate. Also, because of its aggressiveness, intermediate wheatgrass (Agropyron intermedium) was replaced by slender wheatgrass (Agropyron trachycaulum) on areas seeded in 1983.

This seed mix and seeding rate take into consideration the proper ratio of warm and cool season species in the number of pure live

Table 1. 1987 vegetative characteristics of 19 reclaimed grassland stands (site types) established on the Glenharold Mine between 1981 and 1983.

	Species Detected			Relative % LBC[d]		Relative % Production					
Site	Total	3% LBC[b]	H'[c]	Warm	Cool[e]	Warm	Cool	Date Seeded	Seeding Oper.	Mulch Type	Dist. Type
				%							
A[a]	12	4	1.73	38	62	13	66	05/27/82	PD[f]	NH+SH[f]	MD[f]
B	13	8	1.92	28	55	10	66	05/18/81	PD	SH	MD
C	11	7	1.85	34	56	18	72	05/22/82	PD	NH+SH	MD
D	15	10	2.02	33	60	20	75	05/11/82	PD	NH+SH	MD
E	13	9	1.87	15	81	5	85	05/10/81	PD	NH+SH	MD
F	12	8	1.89	40	58	24	76	05/31/83	PD	SH	MD
G	12	8	1.91	53	46	29	71	06/07/83	BS	SH	MD
H	13	4	1.53	80	18	48	42	06/05/82	PD	NH	MD
I	13	8	1.90	48	33	23	50	06/10/81	PD	NH+SH	MD
J	14	7	1.95	27	73	20	79	05/21/82	PD	NH	MD
L	11	8	1.86	52	48	48	52	06/09/83	PD	NH	AS
N	13	10	1.99	38	45	10	68	05/22/82	PD	NH	MD
O	14	8	1.93	55	40	34	57	06/05/82	PD	NH	MD
P	13	8	1.89	27	69	32	68	05/23/82	PD	NH	MD
Q	10	10	1.83	34	66	10	90	06/01/83	BS	SH	MD
R	12	6	1.77	59	41	52	47	06/01/83	BS	SH	AS
S	10	4	1.74	38	62	5	95	10/10/83	PD	SH	MD
T	13	13	1.97	51	49	35	62	06/03/83	PD	SH	MD
V	17	9	1.95	65	32	31	55	06/02/82	PD	NH+SH	AS
Mean	13	8	1.87	43	52	25	67				
Min	10	4	1.53	15	18	5	42				
Max	17	13	2.02	80	81	52	95				

[a] Note: Sites K and U were merged with sites L and V respectively because of similar vegetative characteristics. Site M is a tamegrass hayland and therefore, was excluded.

[b] Total number of species detected at 3 percent or more relative live basal cover.

[c] H' = Shannon-Weiner Plant Species Diversity Index.

[d] LBC = Live basal cover.

[e] WARM = Warm Season Species, COOL = Cool Season Species.

[f] NH = Native hay, SH = Slough hay, PD = Press drill, BS = Broadcast seeded, AS = Associated disturbance, MD = Mine disturbance.

Table 2. Species and seeding rate for the Section 15 reclamation area.

Species	Scientific Name	Plant Type [a]	Kg/ha PLS [b]	PLS/M²
Western wheatgrass	*Agropyron smithii*	CN	5.6	151
Intermediate wheatgrass	*Agropyron intermedium*	CI	2.2	43
Big bluestem	*Andropogon gerardii*	WN	1.1	41
Sand bluestem	*Andropogon hallii*	WN	1.1	28
Little bluestem	*Andropogon scoparius*	WN	2.2	127
Sideoats grama	*Bouteloua curtipendula*	WN	2.2	95
Blue grama	*Bouteloua gracilis*	WN	1.1	202
Prairie sandreed	*Calamovilfa longifolia*	WN	1.1	74
Switchgrass	*Panicum virgatum*	WN	1.1	96
Sand dropseed	*Sporobolus cryptandrus*	WN	.6	654
Green needlegrass	*Stipa viridula*	CN	2.2	88
Sweetclover	*Melilotus officinalis*	F	1.1	64
TOTAL			21.6	1,663

[a] CN=Cool season native, CI=Cool introduced, WN=Warm season native, F=Forb (legume)

[b] PLS=Pure live seed

seeds (PLS) per square meter. Earlier studies by Williamson (1984) pointed out the importance of using a warm:cool ratio of 3:1 or greater, to establish seasonally balanced grasslands. The warm:cool ratio for this mix is 4.7:1, which includes 1,318 PLS/m² for the warm season group and 282 PLS/m² for the 3 cool season species.

All site types except site P were hayed on a regular basis for two reasons. First, haying was used to prevent litter accumulations which can be excessive, particularly the first few years following seeding. Second, intermediate wheatgrass dominated the stand and would eventually exclude other slower growing species. Consequently, mowing was timed to coincide with flowering and seed production in order to deplete carbohydrate reserves and reduce its competitive advantage.

Of the 19 site types, production and cover have been collected since 1982 on 3 sites identified as C, E and I. Study sites E and I were seeded in 1981 while site C was established in 1982. All sites were sampled in 1987 for bond release purposes. Production data were collected at community peak standing crop using a 0.25 m² frame. Live basal cover (LBC) measurements were obtained using the 10-point frame described by Cook and Bonham (1977). A minimum of 2,000 points were read and recorded at each site. Cover data were collected by species, then grouped into categories including cool season grasses, warm season grasses, sedges, forbs and shrubs. Where species richness is discussed, sedges, forbs and shrubs were each considered as one species. These groups, as well as individual species, were counted as one species when their relative total cover equalled or exceeded 3 percent.

Study sites C, E and I were selected for long term monitoring for several reasons. First, this reclamation area was one of the earliest attempts at the GHM to establish a broad species base including tall grasses and data was needed to evaluate their performance. Second, sites E and I were seeded in 1981 but at different dates in the spring; site E around May 10 and site I around June 10. Additionally, sites C and E were mulched with native hay obtained from range sites similar to those found in section 15 prior to mining. Finally, both C and E contain subplots that were established to study the effects of non-selective herbicide treatments and the contribution of native hay mulch toward species diversity and seasonal variety.

Results and Discussion

Site Type Differences

As of the end of the 1987 growing season, site types were 5 to 7 years of age. Of the 19 identified, native forbs were recorded on 15, 13 have sedges, and 2 have shrub species. The mean number of species detected, based on a 3 percent minimum relative cover value, is 8 and varied from 4 to 13. Figure 1 illustrates the relationship between species numbers and the Shannon-Weiner Plant Diversity Index (H') (Shannon and Weaver, 1973). This equation, using log base 10, is

$$H' = \Sigma \text{Pi Log Pi}$$

where Pi is the actual cover of species i divided by the total cover. Sites A, H and S had only 4 species and concurrently the species diversity index was lowest for these areas. Site H is dominated by little bluestem which provides 72 percent of the total live basal cover while sites A and S are dominated by Agropyron spp. where relative cover values are 57 and 62 percent respectively. Sites D, N, T and Q, on the other hand, had 10 or more species. These sites generally had the highest diversity values indicating a more even distribution of individuals among species.

Seasonal variety, expressed in terms of both relative cover and relative production of warm season species, averaged 43 and 25 percent respectively (Table 1 and Figure 2). Mean total warm season production in 1987 averaged 470 kg/ha (419 lbs/ac) across all sites which exceeded the reference area standard by 59 kg/ha (52 lbs/ac).

Relative cover and species richness recorded in 1988 for select site types and study plots discussed in the remainder of this paper are presented in Table 3.

Planting Date

When the goal is to establish seasonally balanced grassland stands, it is important to delay the seeding date to favor warm season species. Often it is tempting to get in the field as soon as conditions permit to take advantage of early spring rains. However, if an early planting date is chosen and normal rainfall and temperatures occur, chances are a stand will develop that is dominated by cool season species. Williamson (1984) pointed out the importance of a delayed seeding date on GHM grasslands established in 1979. Vegetation differences in the section 15 reclamation area also were obvious between early and late seeding dates (Figure 3).

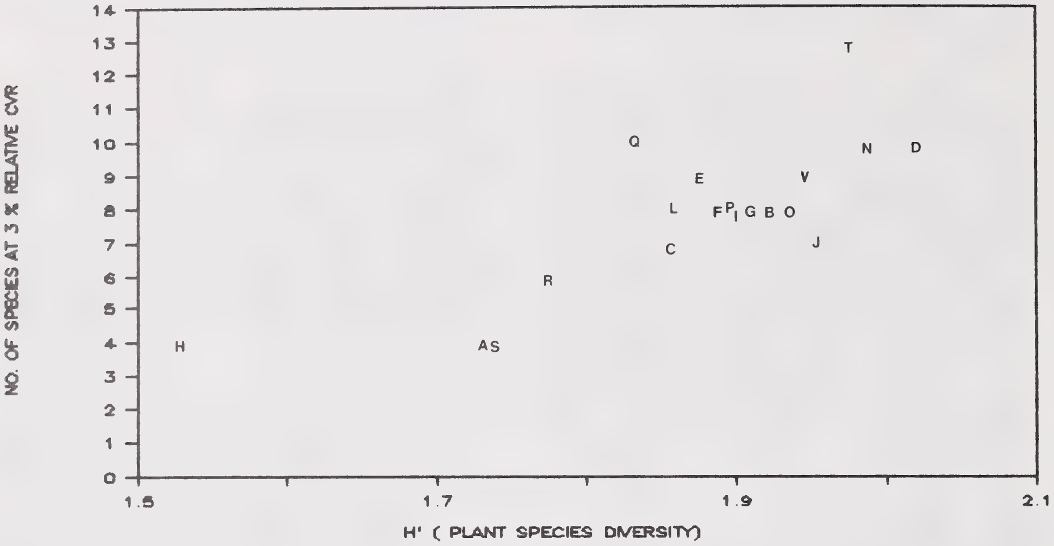

Figure 1. Number of species present and Shannon-Weiner diversity values (H') for 19 vegetation site types established on a single reclamation area between 1981 and 1983.

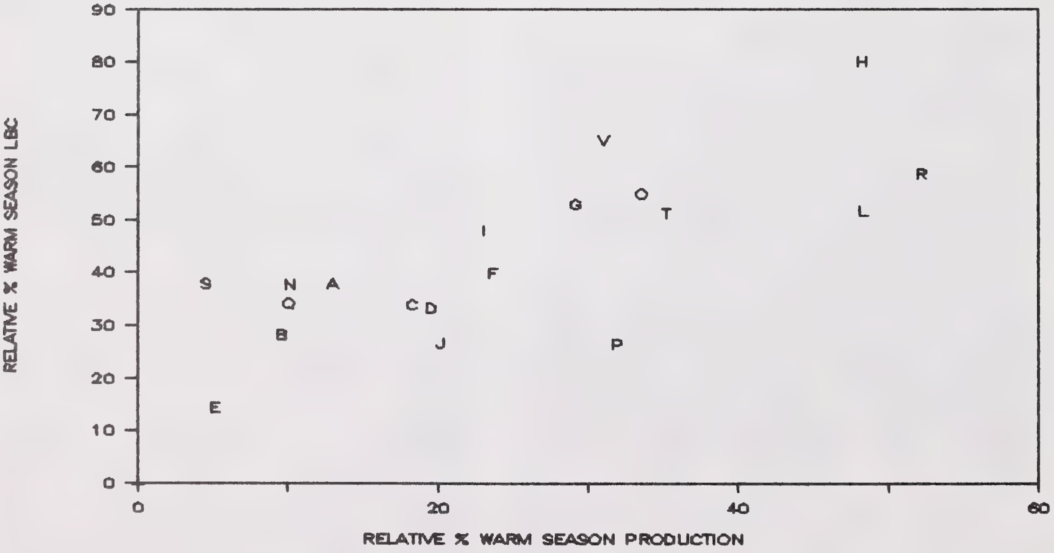

Figure 2. Relative cover and production of warm season species on 19 vegetation site types seeded between 1981 and 1983.

Table 3. Species composition based on relative LBC on select study sites within the Glenharold Mine section 15 reclamation area in 1988.

		Sands	Reclamation Sites					
Species	Plant Type	Reference Area	15C	Herb-83	Herb-85	15-E	15-I	Native Mulch
Western wheatgrass *Agropyron smithii*	CN	3	30	2	8	16	16	3
Wheatgrass (other) *Agropyron* spp.	CI	0	16	2	0	28	23	0
Slender wheatgrass *Agropyron trachycaulum*	CN	0	1	2	0	7	7	0
Big bluestem *Andropogon gerardii*	WN	0	0	1	0	0	2	0
Sand bluestem *Andropogon hallii*	WN	5	2	2	0	0	0	0
Little bluestem *Andropogon scoparius*	WN	10	2	17	17	2	19	34
Sideoats grama *Bouteloua curtipendula*	WN	0	0	4	7	15	4	2
Blue grama *Bouteloua gracilis*	WN	11	20	16	27	5	5	20
Smooth bromegrass *Bromus inermis*	CI	0	8	3	2	15	0	0
Prairie sandreed *Calamovilfa longifolia*	WN	11	0	8	4	0	0	0
Canada wildrye *Elmus canadensis*	CN	0	0	0	0	0	0	1
Prairie junegrass *Koeleria pyramidata*	CN	1	0	0	0	0	0	0
Switchgrass *Panicum virgatum*	WN	0	0	26	12	0	0	7
Bluegrass *Poa* spp.	CI	3	3	1	0	6	1	14
Indiangrass *Sorghastrum nutans*	WN	0	1	3	5	0	0	0
Sand dropseed *Sporobolus cryptandrus*	WN	0	0	2	3	0	1	1
Needle-and-thread *Stipa comata*	CN	12	0	0	0	0	0	2
Green needlegrass *Stipa viridula*	CN	0	0	0	0	2	5	1
Other warm		2	0	0	0	1	0	0
Other cool		0	0	0	0	0	2	3
Forbs		9	17	5	14	2	13	6
Sedges *Carex* spp.	CN	25	0	6	0	0	2	6
Shrub		10	0	0	0	0	0	0
Total number of species & groups		12	10	16	10	11	13	13
Total number of species & groups => 3% relative LBC		10	6	9	9	7	8	8
Relative cool season LBC		43	58	15	10	75	55	29
Relative warm season LBC		39	25	80	76	23	32	65
Total forbs LBC		9	17	5	14	2	13	6
Total shrub LBC		10	0	0	0	0	0	0

Plant types are CN=Cool season native, CI=Cool introduced, WN=Warm season native.

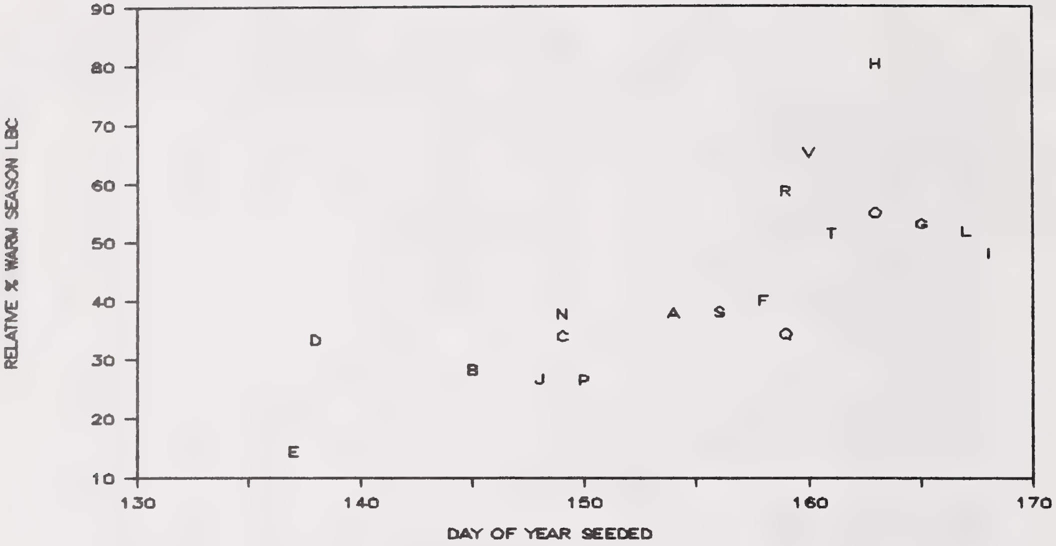

Figure 3. Relationship between the percent relative cover of warm season species and the day of year seeded.

Figures 4 and 5 illustrate differences in warm season grass production and cover beginning in 1985, the fifth growing season and continuing through 1988. Study site E was seeded in mid-May of 1981 while site I was seeded around mid-June.

Although total production on sites E and I was statistically equivalent in 1988 (Table 4), relative cover and production of the warm season component on site E remained below the reference area standard. However, this percentage continued to increase over the last 4 growing seasons and is expected to meet or exceed the standard by year 10.

Table 4. Comparison of 1988 total production on sites E, I and the sands reference area.

Study Site	Kg/ha	Lbs/ac
Site E	1,322	1,180
Site I	1,343	1,198
Sands RA	1,390	1,240

The 1988 yield on the sands reference area was only 64 percent of its natural capability (SCS, 1975) due to extreme drought conditions. This yield reduction corresponds with a 63 percent decrease in May-July precipitation. Total cool season grass yields on sites E

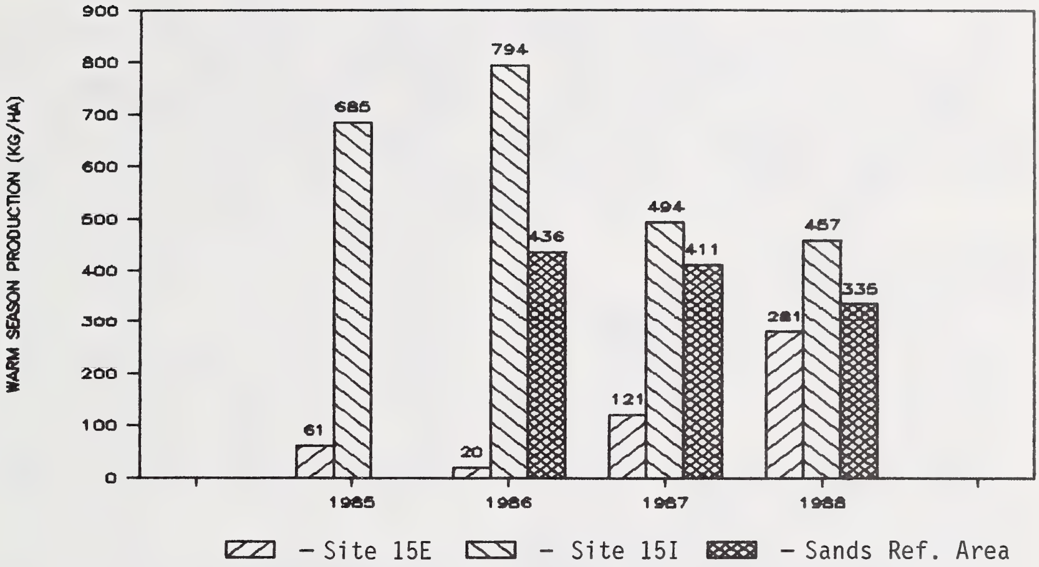

Figure 4. Comparison of warm season production over time on sites seeded early (15-E) and late (15-I) in the spring.

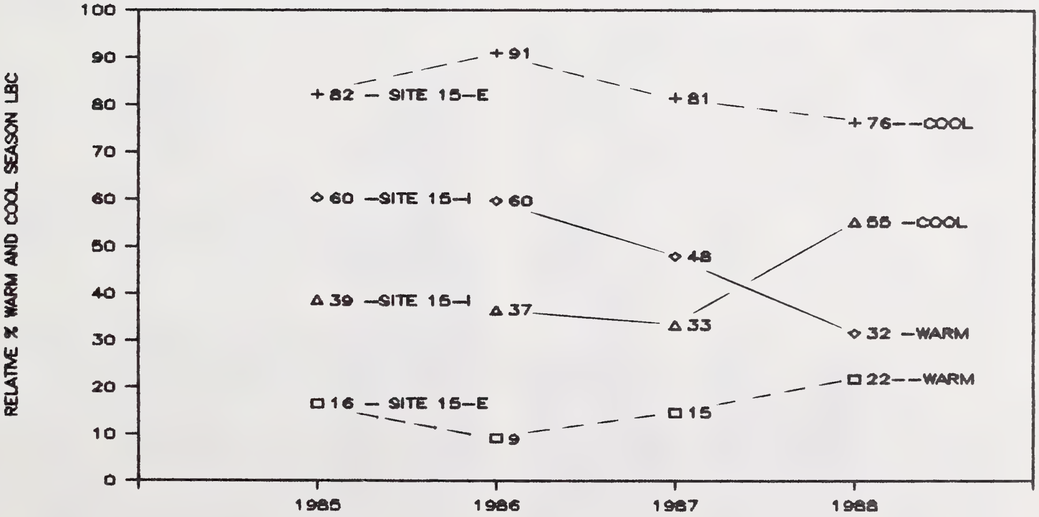

Figure 5. Comparison of relative cover on sites 15-E and 15-I seeded in early and late spring respectively.

and I declined 69 and 64 percent respectively between 1987 and 1988. In comparison, warm season production remained relatively stable on site I and increased from 121 kg/ha (108 lbs/ac) to 281 kg/ha (251 lbs/ac) on site E.

Herbicide Treatments

One of the more promising management techniques to emerge recently involves the use of glyphosate (Roundup) as a cool season suppressant. Although it is considered a non-selective herbicide, it only affects those species actively growing. Consequently, an early application prior to warm season emergence and growth can reduce or eliminate cool season competition. This technique was described by Waller and Schmidt (1983) as an effective way to increase warm season tall grass species on rangeland in eastern Nebraska.

To test its applicability to recently seeded rangeland, glyphosate was applied in early May of 1983 to three randomly selected subplots within site type C. A single application of .85 kg/ha of active ingredient was sprayed with 280 l of water. Later, in 1985, the same treatment was used on subplots either north or south of the 1983 treated areas.

Figure 6 illustrates changes in relative LBC of warm season species on treated plots relative to the control (site C) from 1982 through 1988. Warm season species present after one and three growing seasons responded dramatically to the suppression of the cool season group which was dominated by intermediate wheatgrass. Major species adversely affected by delaying a glyphosate treatment until 1985 were big bluestem, switchgrass and sand bluestem. The 1988 yield difference of 490 kg/ha (437 lbs/ac) between the two herbicide treatments is attributed to the absence of these species (Figure 7). Collectively, they contributed 460 kg/ha (410 lbs/ac) more forage on the 1983 glyphosate treated plots which resulted in significantly higher yields. Although 1988 was a drought year, total production on the 1983 and 1985 glyphosate treatments were higher than the sands reference area and site C. These yields are summarized in Table 5.

Table 5. Comparison of 1988 total production on sites C, 83 and 85 glyphosate treatments, and the sands reference area.

Study Site	Kg/ha[a]	Lbs/ac
Site C	1,362a	1,215
H-83	2,199b	1,962
H-85	1,709ab	1,525
Sands RA	1,390a	1,240

[a] Yields between sites followed by the same letter are not significantly different $P < .05$.

Along with an increase in relative cover and production, both the 83 and 85 herbicide treatments had an increase in species richness over site C (Table 6). After 8 growing seasons, species contributing 3 percent or more toward the total live basal cover totalled 9 in the herbicide study plots while site C had 6 and the sands reference area had 10.

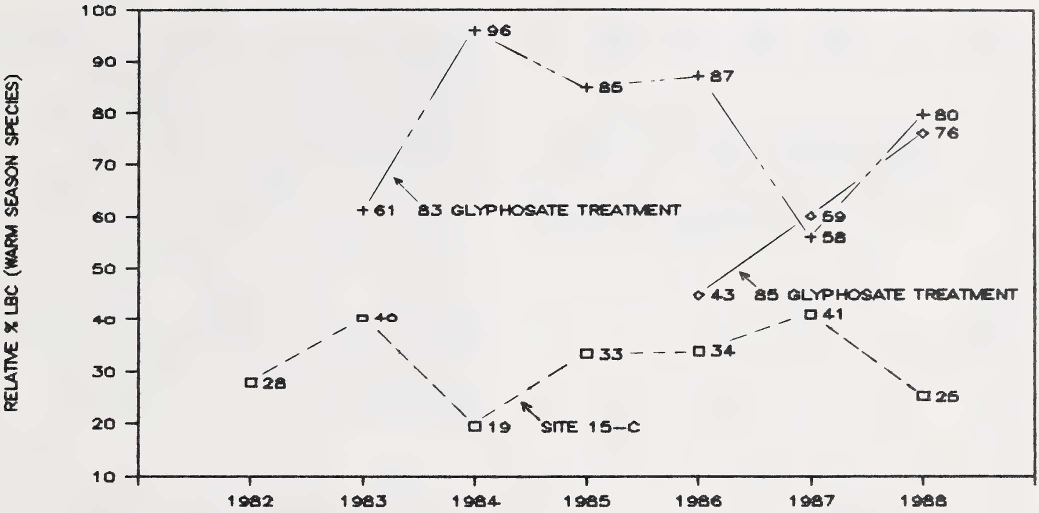

Figure 6. Relative cover of warm season species on plots treated with glyphosate relative to the control area (15-C).

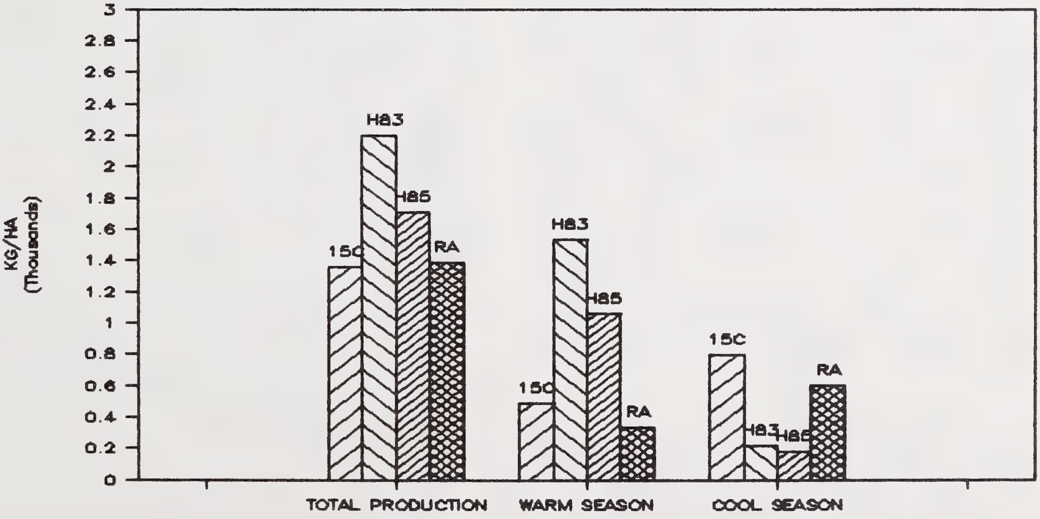

Figure 7. Comparison of 1988 production on 1983 (H83) and 1985 (H85) glyphosate treated plots relative to the control (15-C) and the sands range site reference area (RA).

Table 6. Comparison of species richness between 1983 and 1985.

Year	Reclamation Sites 15-C	Reclamation Sites H-83	Reclamation Sites H-85	Sands Ref. Area
	---------No. Species--------			
1982	7			
1983	10	10		
1984	7	6		
1985	7	7		
1986	5	9	8	11
1987	7	9	11	9
1988	6	9	9	10

Native Hay Mulch

The use of native prairie hay as a complimentary seed source has been reported by Ries and Hofmann (1982). In this publication, they discussed the viability of seed from stored hay after one year. Also Ries et al. (1980) evaluated seed quality and quantity relative to range condition and harvest date. Based on this research, native prairie hay was used on several sites following seeding in 1981 and 1982. Prairie hay was cut and baled during mid August from rangeland where sands and sandy range sites were common. A subplot within site E was mulched, but never seeded in order to observe and develop a better understanding of using this hay as a mulching source.

Cover and production data for 1988 comparing the mulched plot with the seeded and mulched control (site E) are presented in Figures 8 and 9. Relative cover by species are given in Table 3.

From these observations, it was concluded that competition from seeded cool season species, primarily intermediate wheatgrass, adversely affected the establishment and growth of species from the native hay mulch. In addition to a greater warm season component, species composition on the native hay mulch subplot included native forbs and sedges (*Carex spp.*). No significant difference ($P < .05$) in total production was found in 1988 when compared to either site E or the sands reference area. A comparison of species present and their relative cover on the native hay mulch subplot, site E, and the sands reference area is given in Table 3.

The importance of native prairie as a complimentary seed source deserves more attention for several reasons. First, the amount of seed detected per unit of mulch can be sufficient to warrant seed mix modifications to realize a cost savings. The potential seed source from native hay used on this reclamation area was described by Nilson et al. (1985). Native prairie hay cut in August of 1981 and mulched at 3,362 kg/ha (3,000 lbs/ac) in the spring of 1982 provided a seed source potential of 314 seeds per square meter. This is roughly 20 percent of the PLS density for the seed mix listed in Table 2. However, data from this reclamation study area and earlier research have demonstrated that with a good source, proper handling and harvesting, seeding may not be necessary. If seeding is done, care should be taken to minimize the affect of competition from aggressive cool season species.

Summary

Reclaimed native grassland established between 1981 and 1983 in west central North Dakota resulted in 19 grassland stands where vegetative characteristics differed due to establishment and management practices. Live basal cover and production data, collected in 1987

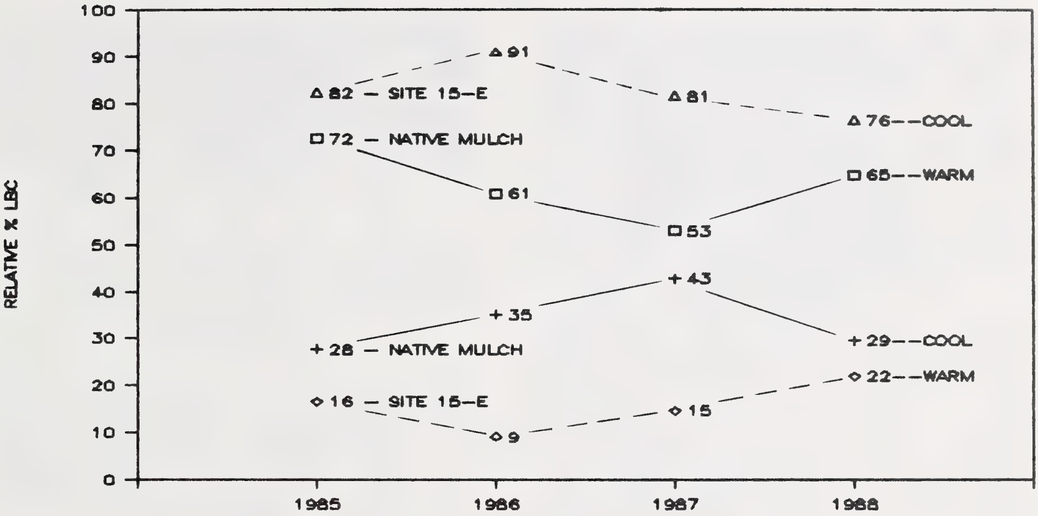

Figure 8. Changes in relative cover of cool and warm season species from 1985 through 1988 on the native hay mulch (NM) and control areas (15-E).

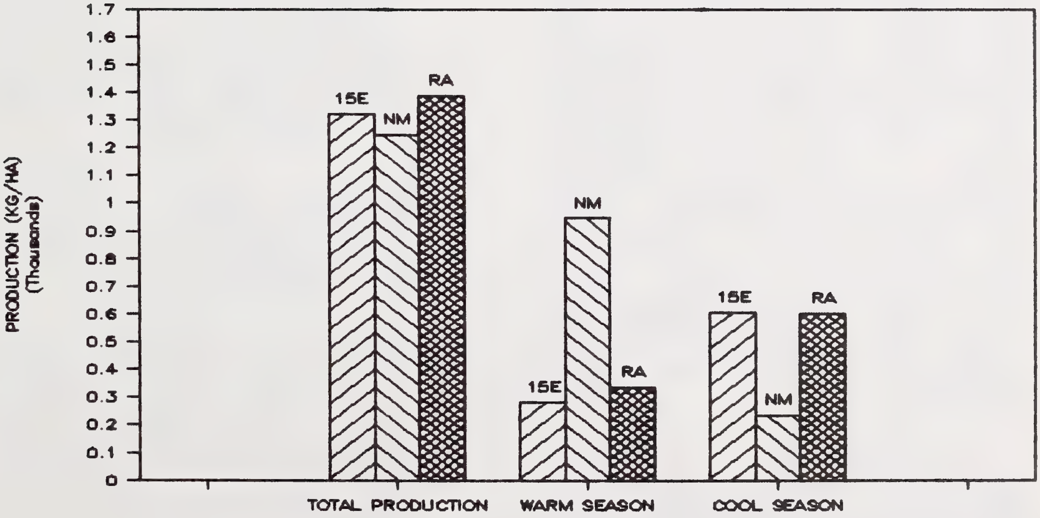

Figure 9. Comparison of 1988 productivity on the native hay mulch (NM), reclamation area 15-E and the sands reference area (RA).

for bond release purposes, indicate species richness and diversity (H') varied between sites. The mean number of species present was 13, but ranged from 10 to 17. When a 3 percent minimum relative cover value criteria is used, the average number of species detected was 8 with a minimum of 4 and a high of 13. Seasonal variety, expressed in terms of relative cover of warm season species, averaged 43 percent and ranged from 15 percent on an area seeded in mid May, to 80 percent on an area seeded in early June. The date of seeding was a primary factor affecting stand composition in this area as well as other reclamation grassland areas established since 1983.

Intermediate wheatgrass was an aggressive competitor the first few years excluding and often negating the contributory effect of the native hay mulch and diverse seed mixture. Where competition from this species was reduced, using glyphosate, the response of the warm season component was dramatic. Similarly, competition from this species affected diversity and seasonal variety on native hay mulched areas. A study site that was mulched but not seeded provided a comparison with an adjacent seeded and mulched area. Although production was equivalent, the native hay mulched area had higher number of species, including sedges and forbs, and higher relative cover and production of the warm season component.

Re-establishing native grasslands that are diverse, productive and qualify for bond release requires an understanding of species as well as community responses to different environmental conditions and establishment and management practices. Practices used will depend on this knowledge relative to prevailing weather conditions for the area. Establishment and management practices used at the Glenharold Mine have consistently produced diverse and productive grasslands that meet applicable bond release criteria.

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PRODUCTIVITY OF AGRONOMIC AND NATIVE PLANTS UNDER VARIOUS FERTILIZER AND SEED APPLICATION RATES ON A SIMULATED TRANSPORT CORRIDOR, FORT NORMAN, NORTHWEST TERRITORIES[1]

by
Kevin E. Evans[2] and G. Peter Kershaw[3]

Abstract. In spring 1987 a reclamation study was initiated on an east-west oriented right-of-way, cleared in a decadent, Subarctic black spruce forest near Fort Norman, N.W.T. The objective was to test the short-term effects of various rates of fertilizer and seed application on the productivity of agronomic (commercially-available) and native plants. The 25m-wide right-of-way was disturbed by 1800 passes of an all-terrain-cycle (ATC) over a 70m length. The site was seeded and fertilized using a seed mix and fertilizer similar to that employed in other northern reclamation projects. Phytomass of native graminoids, native herbaceous and agronomic seed-mix species, increased after the first and second growing seasons. The average increase in native species' phytomass from 1987 to 1988 was 573% in unseeded treatments. Within seeded treatments the average increase in native plant production was 346%. The average increase in agronomic seed-mix phytomass was 454% over the two growing seasons of the study, with the highest productivity occurring in those treatments in which 500 and 1000 kg ha^{-1} of fertilizer were applied.

Additional Key Words: biomass, commercial seed, pipeline, reclamation, revegetation, Subarctic.

Introduction

Exploration and development of northern hydrocarbon and other non-renewable resources has resulted in numerous human-induced terrain disturbances throughout the Arctic and Subarctic. These disturbances vary in degree but require mitigation and reclamation to reduce both the short-and long-term environmental impacts that result. A number of studies have been undertaken throughout the North to investigate means and methods of reducing the impacts associated with human-induced disturbances. Revegetation methods have been tested on disturbances in the taiga of Alaska (Elliott, *et al.* 1987) and Canada (Wein 1971; Hernandez 1973; Younkin 1972; 1973; 1976; Younkin and Martens 1985; Wishart 1988). However, the authors are unaware of studies in which the fertilizer application rate has been varied to determine the optimum amount for plant production.

Short-term goals of northern revegetation programmes include control of fluvial and thermokarst-induced erosion (Mackay 1970; Hernandez 1973; Kerfoot 1973; Zoltai and Pettapiece 1973; Haag and Bliss 1974) and the enhancement of soil stability (Younkin 1976). However, long-term reclamation of disturbances is desirable in order to establish low-maintenance plant cover, reduce the visual impact of the disturbance, establish wildlife habitat (e.g. shelter or browse) (Hernandez 1973; Dabbs, *et al.* 1974; Johnson and Van Cleve 1976; Younkin 1976), or produce plant communities which are similar to those which result from natural recovery (Densmore and Holmes 1987).

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Agronomic species selected for northern reclamation projects should have an ability to maintain soil stability through growth and litter production (Watson *et al.* 1980). Furthermore, agronomic species should have a broad range of nutrient requirements, allowing growth at a wide range of soil nutrient levels (Watson *et al.* 1980). In addition, the agronomics that are sown should be long-lived and winter-hardy due to the short and cool growing season that is characteristic of the North (Interprovincial Pipe Lines 1983; Hardy Assoc. 1984; 1985).

The movement of vehicles and equipment throughout the North to isolated exploration and development sites causes one of the most wide-spread disturbances to the permafrost, soil and vegetation in the Arctic and Subarctic (Van Cleve 1977). The type of vehicle, time of year, and the terrain affected are the principal factors determining the level of disturbance created in Arctic and Subarctic regions (Bellamy *et al.* 1971; Hok 1971; Kerfoot 1972; Heginbottom 1973; Rickard and Slaughter 1973; Rickard and Brown 1974; Addison and Bell 1976; Van Cleve 1977; Dyke 1985; Lawson 1986). Within the Mackenzie River Valley, studies on the effects of vehicle traffic have been limited to winter roads (Strang 1973; Adam and Hernandez 1977).

The purpose of this study was to test the short-term effects of various rates of fertilizer and seed application on the productivity of agronomic and native plants on a simulated transport corridor. The main hypothesis that was tested was that increases in the fertilizer application rate would result in positive and corresponding growth rates in the standing crop of plants (including the seeded agronomic species and the invading, native plant species).

Study Site

The field research was conducted at the SEEDS (Studies of the Environmental Effects of Disturbances in the Subarctic) facility near Fort Norman, N.W.T. The study area, which is within the discontinuous permafrost zone (Brown 1978), has been classified as flat to sloping lacustrine and moraine plain (Reid 1974; Interprovincial Pipe Line (NW) Ltd. 1980). The permafrost-influenced soil of the study site has been classified as a Gleysolic Turbic Cryosol (Canadian Soil Survey Committee 1978; Kershaw and Evans 1987). The mean active layer depth for the study area was 48cm (Evans *et al.* 1988).

The pre-disturbance Subarctic forest was greater than 200 years-old. It was dominated by an overstory of *Picea mariana* (black spruce) and an understory of *Salix arbusculoides* (little tree willow), *Ledum groenlandicum* (Labrador tea), *Vaccinium vitis-idaea* (lingonberry), *V. uliginosum* (bog bilberry) and *Arctostaphylos rubra* (red fruit bearberry). Non-vascular ground cover was dominantly *Hylocomnium splendens* (stair-step moss), *Cladonia arbuscula (shrubby reindeer lichen)* and *Aulacomnium palustre* (marsh moss) (Kershaw 1988).

Methods

In 1986, an east-west portion - the South Link, of the SEEDS site was hand-cleared of all erect woody plants that were greater than 0.5m-tall (Figure 1). In 1987, upon removal of the tree stumps, this east-west oriented right-of-way was disturbed by 1800 passes of an all-terrain-cycle (ATC) (Honda 200m) over an 18h period. An improvised 'ripper' was dragged behind the ATC to increase the extent of surface disturbance by churning the organic mat and uprooting or clipping-off aerial portions of plants. However, due to the shallow thaw depth at this time, only the organic mat was lightly mulched and compacted.

Upon completing the surface disturbance, on 26 May 1987, twelve treatment plots were installed on each side of a simulated pipeline trench which bisected the right-of-way (Figure 1). The treatments included fertilizer and seed application rates similar to those used in other northern reclamation projects (Table 1). A complete fertilizer with a nitrogen-phosphorous-potassium blend (17-25-15) was hand broadcast at various rates (Table 1). The seed mix was identical to that used by Interprovincial Pipe Line (NW) Ltd. (1983) on their Norman Wells-Zama Lake pipeline. It was hand broadcast at a rate of 30 kg ha^{-1} and contained the following agronomic or commercially-available species: *Poa pratensis* (kentucky bluegrass) - 5%, *Festuca rubra* (BOREAL creeping red fescue) - 20%, *F. ovina* (sheep fescue) - 15%, *Agropyron trachycaulum* (REVENUE slender wheatgrass) - 28%, *Alopecurus arundinaceus* (GARRISON creeping

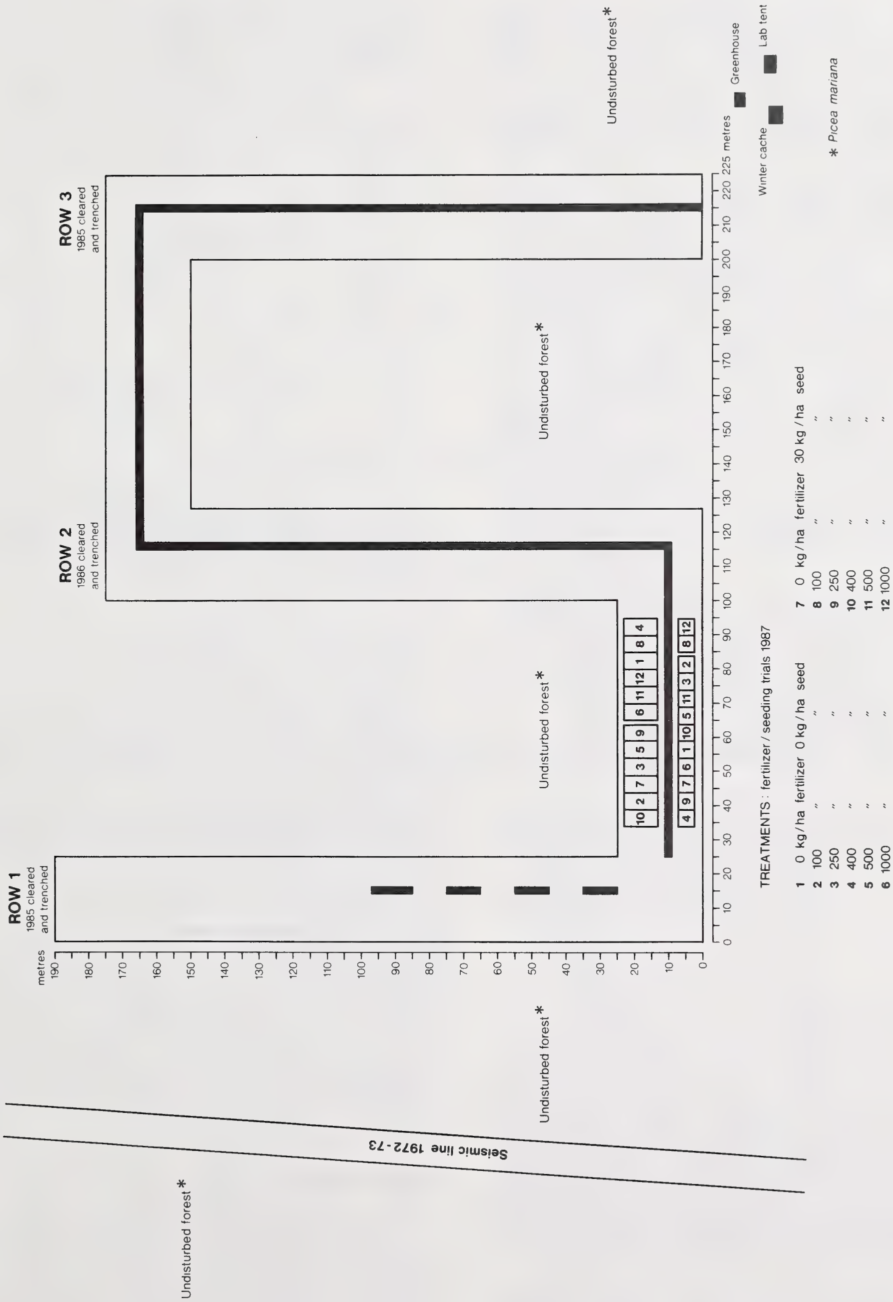

Figure 1: Location of fertilizer/seeding trials on the simulated transport corridor.

foxtail) - 15%, *Phalaris arundinacea* (VANTAGE reed canarygrass) - 12% and *Phleum pratense* (CLIMAX timothy) - 5%. These species are deemed to be suitable for northern reclamation because they are able to maintain soil stability, have low nutrient requirements, and are long-lived (Watson *et al.* 1980).

A 1m buffer zone within each of the twelve test treatment plots reduced any edge effect from the adjacent plots or untreated areas (Figure 2). In the test treatments south of the trench, the soil sampling, plant cover estimates, and phytomass (above-ground biomass) sampling, were conducted within a 3 x 3m quadrat centred in the treatment plot. However, north of the trench, the sampling plots were randomly placed at 1m intervals within the 10 x 5m treatment, while maintaining a 1m buffer zone. The treatment plots north of the simulated pipeline trench were larger than those on the south side due to the availability of space.

Table 1: Revegetation treatments at the SEEDS site and other northern reclamation projects.

Treatment number	Fertilizer application rate (kg ha^{-1})	Seed application rate (kg ha^{-1})
1	0	0
2	100	0
3	250 a,i	0
4	400 e,h	0
5	500 b,c,g,h	0
6	1000	0
7	0 f	30
8	100 d	30
9	250 d,j,k	30
10	400 d	30
11	500	30
12	1000	30

a) Wein 1971, b) Younkin 1972, c) Hernandez 1973, d) Dabbs *et al.* 1974, e) Younkin 1976, f) Johnson 1978, g) Chapin and Chapin 1980, h) Plazzo *et al.* 1980, i) Interprovincial Pipeline (NW) Ltd. 1983, j) Hardy Associates (1978) Ltd. 1984, k) Hardy Associates (1978) Ltd. 1985

The 1 x 1m cell in the centre of the sampling plot was divided into 16, 25 x 25cm cells of which 5 were selected for phytomass (above-ground biomass) sampling in each of 1987 and 1988. All plants rooted within the cells were clipped to ground level.

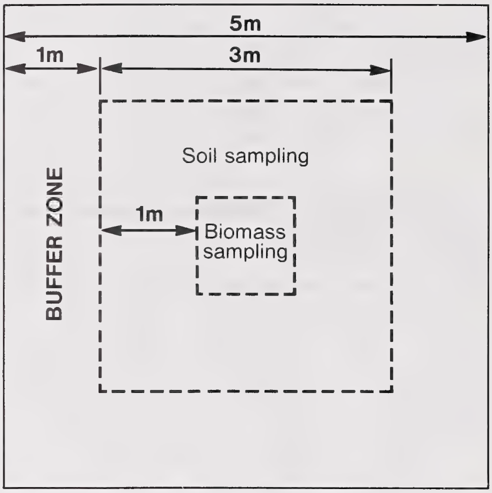

Figure 2: Typical test treatment layout on the South Link at the SEEDS research facility.

Results

Only results of the performance, as measured by the phytomass (biomass) or standing crop for the seeded test treatments (numbers 7 to 12 on Figure 1 and Table 1) are presented below. Total native (native), native graminoids (graminoids) and agronomic seed-mix (agronomics) biomass increased after the first and second growing seasons with higher initial applications of fertilizer. Phytomass of native plant species was greater than that of agronomic taxa in the first growing season within each of the seeded treatments except for those which received fertilizer at rates of 500 and 1000 kg ha^{-1}. Production of native and agronomic plants paralleled each other during both growing seasons. Species in the agronomic seed mix were less successful in the unfertilized treatment (Figure 3).

Native Species' Phytomass

Within unseeded treatments the average increase in biomass among native plants from 1987 to 1988 was 573%. In seeded areas the increase in native production was only 343%. This lower increase in native species' biomass suggests that agronomic species were able to outcompete native plants for available soil nutrients. The reason(s) for this apparent competitive advantage displayed by agronomic

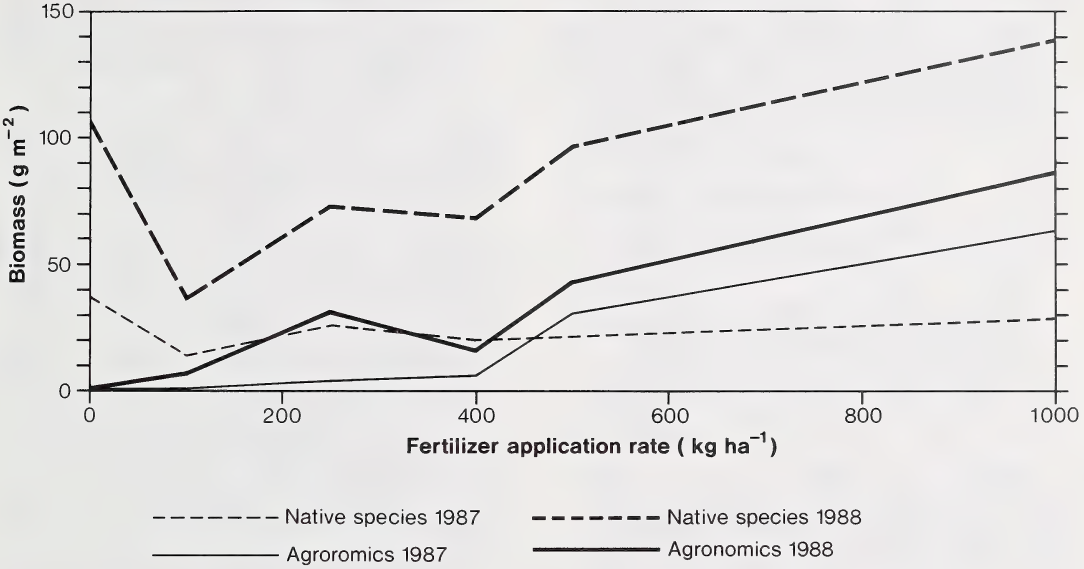

Figure 3: Agronomic versus total native biomass production on seeded plots.

species is beyond the scope of this study but is, no doubt, related to any one or a combination of ecological differences between the species' groups.

Table 2: Total native species' phytomass production (g m^{-2}) (standard deviation) and per cent increase from the first to the second growing season within unseeded treatments, SEEDS, NWT.

Treat- ment	1987		1988		Per cent increase
0	9.50	(0.85)	71.09	(5.50)	748
100	4.21	(0.30)	24.81	(1.91)	589
250	12.14	(0.63)	55.86	(3.10)	460
400	16.77	(1.29)	127.10	(10.84)	757
500	27.44	(5.14)	34.38	(3.89)	125
1000	19.97	(11.69)	151.79	(10.53)	760

The per cent increase in native species' phytomass from 1987 to 1988 varied among treatments, thereby implying that some factor, other than the addition of fertilizer, affected plant production (Tables 2 and 3). This was partially confirmed when, on one unseeded plot, dry substrate conditions resulted in low production despite a relatively high fertilizer application rate (500 kg ha^{-1}).

Agronomic Seed Mix Species' Phytomass

Although there was no agronomic seed applied in the unseeded treatments there were a few non-native species found within some of these treatments. These individuals must have originated as a result of transport of seed from adjacent plots following the initial seed application and/or natural seeding at the end of the first growing season. Wind was probably the most important agent of seed transport since few animals were found on the area during small mammal trapping, however, seed may also have been carried by runoff or, inadvertently, by researchers moving among the plots.

The average phytomass increase for agronomic seed mix species from 1987 to 1988 was 454%. In 1987, the agronomics were not successful in the lower fertilizer treatments.

They were, however, more productive at fertilizer application rates of 500 and 1000 kg ha^{-1} than the native plants (Table 2 and Figure 3). The increase in native plant production by the end of the second growing season was, however, lowest in the two treatments of highest fertilizer application. The initial increase in soil nutrients, as a result of fertilizer application, may have been responsible for the high productivity during the first growing season in the 500 and 1000 kg ha^{-1} treatments. However, by the second season reduced nutrient availability in the soil precluded similar increases in production.

Table 3: Phytomass production ($g\ m^{-2}$) (standard deviation) of all native species, native graminoids and agronomic (commercially available seed-mix) plants within seeded treatments, SEEDS, NWT.

Treatment	All native species	Native graminoids	Agronomic species
		1987	
0	37.92 (4.15)	2.22 (0.32)	0.14 (0.02)
100	14.80 (0.89)	0.80 (0.08)	0.90 (0.12)
250	26.37 (3.47)	0.78 (0.12)	4.94 (0.48)
400	20.43 (1.45)	1.92 (0.25)	5.18 (0.96)
500	21.74 (1.63)	1.42 (0.23)	31.70 (3.02)
1000	28.58 (2.03)	9.07 (1.01)	63.10 (8.94)
		1988	
0	106.22(11.44)	4.77 (0.81)	1.04 (0.28)
100	36.61 (2.65)	2.15 (0.19)	6.90 (0.72)
250	74.29 (5.20)	12.58 (2.53)	31.17 (3.45)
400	68.41 (5.93)	12.62 (3.63)	16.10 (3.38)
500	96.92 (6.89)	8.76 (1.42)	43.39 (4.27)
1000	139.33(13.47)	87.56(14.51)	86.43 (7.18)

Discussion

All components of the reestablishing vegetation were greater with higher fertilizer application rates (Table 2 and 3). However, only the native graminoids and agronomic species had significant increases in production as a result of fertilizer application (Table 4). This was true for both years although the relationship was less strong during the second growing season.

There was a correlation between the rate of fertilizer applied and both native graminoid and agronomic phytomass (Table 5). Both the graminoids and agronomics had a significant positive correlation with fertilizer application in each of 1987 and 1988. However, the total native biomass was not significantly correlated with fertilizer application in either of the two growing seasons (Table 5).

Table 4: Results of the analysis of variance in phytomass among species' groups (total native plants[1], native graminoids[2] and agronomics (commercially available seed-mix)[3]) in response to increases in fertilizer application rates. Revegetation test treatments, SEEDS, NWT.

Species groups	df	Sum of squares	Mean sum of squares	F-ratio
		1987		
Native[1]	5	12.4	2.5	0.88 #
Graminoids[2]	5	2.0	0.39	4.36 **
Agronomics[3]	5	123.7	24.70	3.80 **
		1988		
Native[1]	5	244.2	48.8	1.57 #
Graminoids[2]	5	208.6	41.7	2.48 *
Agronomics[3]	5	192.5	38.5	5.69 **

#	No significant difference
*	$P<0.05$
**	$P<0.01$

The fertilizer composition and amount applied appears to favour graminoids rather than forbs or woody plants. If a project proponent wished to enhance these components of the vegetation on a disturbance then the fertilizer would have to be altered.

Table 5: Correlations between fertilizer application and each of: total native material[1], native graminoids[2], and agronomic seed mix[3] on revegetation test treatments, SEEDS, NWT.

Species groups	Correlation coefficient	Significance level
	1987	
Native[1]	-0.10	0.9420
Graminoids[2]	0.448	0.0003
Agronomics[3]	0.483	0.0001
	1988	
Native[1]	0.236	0.0701
Graminoids[2]	0.386	0.0023
Agronomics[3]	0.562	0.0000

Conclusions

It must be stressed that the experiment we are reporting on is based upon: 1. the first two growing seasons following treatment, 2. a cleared right-of-way with an organic-dominated substrate, 3. a cleared right-of-way on which pre-disturbance root stock and buried propagules persist.

Site conditions, in addition to the placement of the seed (i.e. at the surface and not within the soil rooting zone) as a result of hand broadcasting, may account for some of the variations that existed among the treatments. However, based upon preliminary analyses of the phytomass of local native and introduced, commercially available agronomic plants the variation in fertilizer application rate resulted in increased biomass of both species' groups. However, without complete analysis of all variables, including soil nutrients, soil moisture content, etc., it is difficult to assess which fertilizer application rate is most suited for the short-term growth of plants on this and similarly disturbed sites in the Subarctic.

Indications are that competition occurs between introduced, agronomic, commercially-available species and native, locally growing plants in the early (first 2 growing seasons) stages of revegetation. This relationship was particularly evident when considering the non-graminoid component of the local plants (e.g. forbs and shrubs). Further analysis and the addition of data from more growing seasons will clarify this relationship.

Based on the first two growing seasons' production, it appears that competition for nutrient resources is not limiting for any species group. All revegetation components appear to have responded to fertilizer application during this early stage of reclamation.

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RESPONSE OF RESEEDED COAL MINE SPOILS TO SEASON AND INTENSITY OF DEFOLIATION: PRELIMINARY FINDINGS[1]

by

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Abstract. Two principal questions facing managers of revegetated coal mine spoils in the semiarid Southwest are how seasonal defoliation patterns and intensities of defoliation affect forage production and plant stability on reclaimed sites. Preliminary findings were obtained from a study conducted on revegetated coal mine spoils near Gallup,NM, during 1982-1984. Five mine spoil sites, recontoured and seeded to a mixture of predominantly wheatgrasses (*Agropyron* spp.) between 1975 and 1980, were selected for study. Each site was subdivided into six split plots that were randomly assigned defoliation seasons of early spring, late spring, summer, fall, winter or a control. All plots except the control were subdivided and were assigned defoliation intensities of 7.5 cm or 15 cm. Defoliation treatments were applied two consecutive calendar years, early spring 1982 to winter 1984. Treatment effects were assessed in late August 1984. Preliminary findings indicate neither wheatgrasses nor total standing herbage was influenced by seasonal defoliation, but other grasses were less productive when defoliated in the summer and winter than when defoliated in the fall. Total herbage production diminished when defoliated at the 7.5-cm stubble height every season except early spring and fall compared to the control. Generally, defoliation at 15 cm did not impact total herbage production. Neither the time since seeding of the coal mine spoils nor topsoiling consistently influenced total herbage production.

Additional Key Words: forage production, wheatgrasses, New Mexico

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Introduction

By the year 2000 coal strip mining is expected to alter more than 200,000 acres (Fisher et al., 1986) of western range. These lands provide forage for wild, feral and domestic herbivores as well as cover and nesting habitat for numerous species of animals, birds, reptiles and amphibians. The Surface Mining Control and Reclamation Act of 1977 and its supporting regulations require the reestablishment of vegetation with cover that is at least equal to the natural vegetation of the area, capable of stabilizing the soil from surface erosion and compatible with the plant and animal species of the area. The technical literature on mined land reclamation, as assembled by Aldon and Oaks (1983), Williams and Schuman (1987) and Wright (1978), has dealt almost exclusively with aspects of revegetation, such as environmentally adapted plant species, seeding mixtures, preseeding site preparation techniques, fertilization, irrigation, mulching, other cultural treatments and unique soil chemical and physical properties. For example, Lang (1982) found that forage production on 2.5 year old Wyoming mine spoils equalled or exceeded that on native range. Several studies examined forage production and livestock gains on revegetated coal mine spoils and adjacent native range in Colorado (Laycock and McGinnies, 1985; Laycock and Layden, 1986), Montana (DePuit and Coenenberg, 1979) and North Dakota (Hofmann and Ries, 1988). In a 3-year study of light, heavy and nongrazed Wyoming pastures, Schuman et al. (1986) concluded that successfully reclaimed mined lands will support livestock grazing without deteriorating the basal ground cover of vegetation. Laycock and Layden (1986) found no differences in animal performances among summer-long heavy, summer-long light or short duration grazing systems in a 2-year study on reclaimed mined lands. After 5 years of study, Hofmann and Ries (1988) concluded that with 59 percent or less total vegetation removal in early summer, the reclaimed mine spoils provided sustained grazing use with no deterioration. However, for semiarid range only limited information is available on the effects of biomass removal on stability of vegetation and associated mine spoil material or on how the season and intensity of biomass removal may influence productivity of reclaimed coal mine spoils.

The objectives of this study were to: (1) determine how seasonal biomass removal patterns and intensities of biomass removal to simulate grazing affect forage production on reseeded coal mine spoils of varying ages and spoil management practices, and (2) synthesize the data into management guidelines concerning suitability of grazing revegetated coal mine spoils in western New Mexico.

Study Area

This study was conducted on the McKinley Coal Mine, approximately 35 km northwest of Gallup, NM. Elevation at the study area is approximately 2100 m but varies because of a series of rolling ridges and valleys. Area soils have weathered predominantly from sandstone, although heavy clay soils derived from shale occur on adjacent alluvial fans. On unmined areas, Colorado pinyon (*Pinus edulis* Engelm.) and one-seed juniper (*Juniperous monosperma* (Engelm.) Sarg.) are typically the codominant native species on sandstone ridges (Wagner et at., 1978). Big sagebrush (*Artemisia tridentata* Nutt.) is a common understory shrub on the sandstone ridges and is the dominant species on alluvial fans. Other species common in both associations include Greenes rabbitbrush (*Chrysothamnus greenei* (Gray) Greene subsp. greenei), fourwing saltbrush (*Atriplex canescens* (Pursh) Nutt.), galleta (*Hilaria jamesii* (Torr.) Benth.) and western wheatgrass (*Agropyron smithii* Rydb.).

Annual precipitation at McKinley Mine (averaged over 40 years) is 30 cm and approximately 4 cm per month are received between July and October from convectional thundershowers (Sellers and Hill, 1974). Periodic snow showers occur from November to May. Extended dry periods are common during the spring and early summer. During the 3-year study, annual precipitation at the McKinley Mine averaged 22.6 cm, ranging from 29.8 cm in 1982 to 18.3 cm in 1983. Monthly average temperatures ranged from a high of 21°C in July to a low of -1°C in January.

Methods and Design

Five revegetated coal mine spoil sites were selected for study; all differed in spoil management and age since seeding. The regraded spoil material on all sites generally consisted of a mixture of loamy soil, sandstone and shale. However, the physical and chemical properties of individual spoil sites varied widely, depending upon depth of the original cut, ratio of sandstone to shale and time since exposure (Scholl and Pase 1984). Three sites were topsoiled before seeding, but the other two sites were seeded directly on the raw spoil material. The five sites also reflect four seeding dates; sites were seeded during the summers of 1975, 1977 (2 sites), 1979 and 1980.

Sites were seeded with one of four seed mixtures, depending upon year, but all mixtures were predominantly western wheatgrass and other *Agropyron* spp. such as pubescent wheatgrass (*A. trichophorum* (Link) Richt.), tall wheatgrass (*A. elongatum* (Host) Beauv.), thickspike wheatgrass (*A. dasystachyum* (Hook.) Scribn.), streambank wheatgrass (*A. riparium* Scribn. & Smith), crested wheatgrass (*A. cristatum* (L.) Gaertn.) and intermediate wheatgrass (*A. intermedium* (Host) Beauv.). Smooth brome (*Bromus inermis* Leyss.) and yellow sweetclover (*Melilotus officinalis* (L.) Lam.) were also included in the 1975 and 1977 seed mixtures. Sideoats grama (*Bouteloua curtipendula* (Michx.) Torr.), Indian ricegrass (*Oryzopsis hymenoides* (R. & S.) Ricker) and dewinged fourwing saltbush were included in the 1979 and 1980 seed mixtures. Sites were seeded with pure live seed at a rate of approximately 7.71 kg/ha.

Each site was subdivided into six equal plots that were randomly assigned defoliation seasons of early spring (April 9), late spring (June 15), summer (August 3), fall (October 2), winter (January) and a control (nondefoliated). Plots were 12.2 by 9.15 m. All plots except the control were then subdivided into two equal subplots and randomly assigned one of two defoliation intensities (stubble heights), 7.5 cm or 15 cm, providing 11 treatment cells per replication. Subplots were 6.1 by 9.15 m. A rotary lawn mower adjusted to cut at the prescribed stubble height was used to apply defoliation treatments. The 11 treatment cells were replicated three times on each of the five sites, providing a total of 165 treatment cells. Defoliation treatments (seasons and intensities) were applied to the same cells during two consecutive calendar years immediately preceding assessment of treatment effects. Treatments were applied in 1982 and again in 1983, except for the winter defoliation, which was applied in January 1983 and January 1984.

Treatment effects were assessed in late August 1984 by hand clipping the standing live herbage at ground level on four 0.093-m^2 quadrats on each treatment cell. During clipping, herbage on each quadrat was separated into two groups, wheatgrasses and all other perennial grasses. Herbage production is reported as oven-dry weights.

The experimental design was a split-split plot. Means were tested for significance by analysis of variance (ANOV) followed by Tukey's procedure (Steel and Torrie, 1960). Means with heterogeneity of variances were compared by Welch's test (Milliken and Johnson, 1984) followed by Dunnett's T3 procedure (Dunnett, 1980). Differences at the 0.05 level of probability were considered significant.

Results and Discussion

Total standing herbage on revegetated coal mine spoils in western New Mexico was not influenced by seasonal defoliation treatments applied for two consecutive years (table 1). Regardless of defoliation season, total standing herbage averaged 785 kg/ha, but it ranged from 709 to 943 kg/ha. Also, the wheatgrasses, as a group, were not influenced by defoliation season. Production of wheatgrasses averaged 370 kg/ha over the five defoliation seasons, and the extremes in seasonal production ranged only from 342 to 397 kg/ha. The other grasses group, however, was less productive when defoliated in summer and winter (336 and 312 kg/ha, respectively) than when defoliated in the fall (579 kg/ha). Production of other grasses when defoliated during the spring did not differ from production after other defoliation treatments.

The appearant tolerance of wheatgrasses to defoliation treatments may be due to the study procedure of treatment applicaton. The defoliation treatments were applied two consecutive years at 12-month intervals; vegetation responses to treatments were evaluated 8-17 months after application of the final treatment. Thus, the wheatgrasses had only an 8-month

Table 1.--Standing live herbage (kg/ha) at end of the growing season on reseeded coal mine spoils in western New Mexico by season of defoliation.

Defoliation Season	Herbage Groups Wheatgrass spp.	Other grasses	Total
Early spring	361 (93.5)a[1]	399 (63.6)ab[2]	760 (104.0)a
Late spring	342 (65.9)a	447 (68.1)ab	789 (88.8)a
Summer	387 (69.9)a	336 (70.1)b	724 (90.5)a
Fall	364 (59.5)a	579 (90.1)a	943 (96.5)a
Winter	397 (60.0)a	312 (55.8)b	709 (69.3)a
Average	370	415	785

[1] Values within parentheses are standard errors.
[2] Values within columns followed by the same letter are not significantly different (P=0.05).

rest after the final winter clip; however, the plants were dormant then, and clipping treatment only minimally impacted succeeding plant growth. Clipping wheatgrasses in the spring during their rapid growth and culm elongation would probably be detrimental to succeeding plant growth. However, after 12 months of rest and probable regrowth, the impact of spring clipping on wheatgrasses was probably minimal.

Dahl and Hyder (1977) reviewed in detail the developmental morphology of grasses, Branson (1953) described growth, and Rechenthin (1956) discussed morphological characteristics of grasses which affect their tolerance to defoliation. Jewiss (1972) reported that removing of the apical meristem prevents further development of the culm and stimulates axillary buds at the base, however, this stimulation does not necessarily result in a greater biomass production. The probable cause of diminished production in the other grasses following summer and winter defoliations can only be partially explained. The other grass group consisted predominantly of warm-season species, and the summer defoliation treatment apparently removed the apical meristem thus restricting further plant growth (Vogel and Bjugstad, 1968). No explanation for response to winter defoliation is apparent, and it may be an artifact of this study.

Defoliation intensities used in this study generally influenced total herbage production to different degrees for different seasons (table 2). For example, when compared with

Table 2.--Standing live herbage (kg/ha) at end of the growing season on reseeded coal mine spoils in western New Mexico by defoliation season and stubble height.

Defoliation season Herbage group	Stubble Height 15 cm	 7.5 cm	 Control
Early spring			
Wheatgrasses	353 (93.1)a[1]	368 (163.1)a	453 (110.2)a
Other grasses	332 (81.1)b[2]	466 (97.8)ab	726 (158.8)a
Total	685 (111.3)b	834 (176.2)ab	1179 (172.0)a
Late spring			
Wheatgrasses	483 (121.4)a	202 (46.0)b	453 (110.2)a
Other grasses	532 (118.9)ab	362 (65.9)b	726 (158.8)a
Total	1015 (159.7)a	564 (67.7)b	1179 (172.0)a
Summer			
Wheatgrasses	421 (114.1)a	354 (81.5)a	453 (110.2)a
Other grasses	398 (126.1)ab	274 (61.8)b	726 (158.8)a
Total	819 (156.0)ab	628 (91.4)b	1179 (172.0)a
Fall			
Wheatgrasses	474 (103.5)a	254 (56.0)a	453 (110.2)a
Other grasses	567 (121.7)a	592 (135.6)a	726 (158.8)a
Total	1041 (139.9)a	846 (132.9)a	1179 (172.0)a
Winter			
Wheatgrasses	400 (94.7)a	394 (74.6)a	453 (110.2)a
Other grasses	296 (71.9)b	329 (85.8)b	726 (158.8)a
Total	696 (101.0)b	723 (95.7)b	1179 (172.0)a
Average			
Wheatgrasses	426 (47.1)a	314 (41.9)a	453 (110.2)a
Other grasses	425 (47.7)a	405 (41.9)a	726 (158.8)a
Total	851 (60.9)ab	719 (53.3)b	1179 (172.0)a

[1] Values within parentheses are standard errors.

[2] Values within rows followed by the same letter are not significantly different (P=0.05).

the control, total herbage production diminished when defoliated at the 7.5-cm stubble height every season except early spring and fall. Average total herbage production was less on the 7.5-cm stubble height treatment than on the control (719 vs 1179 kg/ha). On the whole, defoliation at 15 cm did not appear to impact total herbage production. The reduction in production of other grasses and the reduction in total herbage after defoliation at 15 cm in winter and early spring is inconsistent with the other results and may not be a true reflection of the biological effects. Under most seasonal defoliation treatments, clipping to a 15-cm stubble height did not significantly depress total herbage production, although total production was depressed after defoliation in late spring, summer and winter at the 7.5-cm stubble height.

Wheatgrasses were not influenced by season or intensity of defoliation, except when defoliated at 7.5 cm in late spring. Apparently the apical meristem in wheatgrass tillers was located between 7.5 and 15-cm above the soil surface during the late spring harvest since production on the 15-cm defoliation treatment was similar to the control at end of the growing season. Production of the other grasses was reduced by the 7.5-cm defoliation during all seasons except the fall. Apparently most species within this predominantly warm-season group had matured by the fall and were relatively tolerant to defoliation intensity. Production on the plots defoliated at 15 cm, was generally not greater than on the 7.5 cm treatment or less than on the control treatments.

Total herbage production was greatest on the 1979 and 1980 topsoiled sites and on the 1977 non-topsoiled site (table 3). Total production was significantly less on the 1977

Table 3.--Standing live herbage (kg/ha) at end of the growing season on reseeded coal mine spoils in western New Mexico by spoil management and seeding date.

Soil management Seeding date	Herbage Group Wheatgrass spp.	 Other grasses	 Total
Non-topsoiled 1975	328 (43.3)b[1,2]	223 (65.5)b	551 (72.3)b
Non-topsoiled 1977	297 (43.4)b	709 (89.8)a	1006 (92.3)a
Topsoiled 1977	296 (58.4)b	259 (42.8)b	556 (71.7)b
Topsoiled 1979	873 (112.8)a	171 (58.6)b	1044 (119.9)a
Topsoiled 1980	94 (27.3)c	853 (75.9)a	947 (74.4)a
Average	378	443	821

[1] Values within parentheses are standard errors.
[2] Values within columns followed by the same letter are not significantly different (P=0.05).

topsoiled and on the 1975 non-topsoiled sites. Neither the time since seeding of the coal mine spoils nor topsoiling consistently influenced total herbage production. Individual herbage groups also varied in production with study sites. The extremes in wheatgrass production occurred on the two most recently seeded sites and leveled off in production on the older reclaimed sites. *Agropyron* spp. included in the seed mixture do not adequately explain differences in production. Production of other grasses also varied with site, although seed mixture and stand composition did have a major influence. For example, in 1980 two cool-season grasses, squirreltail (*Sitanion hystrix* (Nutt.) J. G. Smith) and Indian ricegrass, were the major contributors to the other grass group. Smooth brome, another cool-season grass, was the major contributor of the other grass group on the 1977 sites; however, general observations indicate it was 2 to 3 times more abundant on the non-topsoiled sites even though the same seed mixture was used on both sites. Many confounding effects apparently influenced herbage production on the reclaimed sites; thus differences in wheatgrasses, other grasses, and total production could be due to differences in seed mixture, stand composition, cover, aspect, slope and spoil material composition.

Management Recommendations

Preliminary findings, based upon simulated grazing, indicate that revegetated coal mine sites in western New Mexico can be defoliated during any one of five seasons without significantly influencing wheatgrass production. Summer defoliation may, however diminish subsequent production of warm-season grasses. Plant response to defoliation intensity was variable, but generally, defoliation at a stubble height of 7.5 cm decreases production more than defoliation at 15 cm.

Topsoiling was a variable factor in production of herbage on reclaimed coal mine sites in western New Mexico. Although not specifically tested in this study, cool-season grass species established sooner or appeared to establish and produce more herbage than warm-season species.

Future research should test the compatibility of grazing on the long-term stability and multiple-use values of reclaimed mine spoils, including establishment of proper stocking rates, livestock utilization patterns, the botanical composition of livestock diets and plant responses to grazing.

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UTILIZING THE RHIZOBIUM-SUBTERRANEAN CLOVER ASSOCIATION FOR RECLAMATION OF LIGNITE MINE SPOIL[1,3]

by

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Abstract. Field plots were established on freshly-levelled lignite mine spoil at Big Brown Mine near Fairfield, Texas, in the fall of 1986 to study the effects of fertilization and inoculation with Rhizobium leguminosarum biovar trifolii on the establishment and growth of subterranean clover (Trifolium subterraneum L.), to evaluate the survival of Rhizobium in mine spoil, and to examine the effect of clover presence on yields of subsequent coastal bermudagrass (Cynodon dactylon L.) crops. In 1987, clover yields were greatest in inoculated plots with added P and K. In 1988, greater subclover yields occurred in fertilized inoculated and uninoculated plots. Increased bermudagrass production was found when clover was grown prior to the grass crop. Low numbers of indigenous rhizobia were present at plot establishment and were effective with subterranean clover, but dry matter production was lower in uninoculated plots. All clover plots had from 10^4 to 10^5 rhizobia g soil^{-1} at the end of the first and second clover growing seasons, and these populations remained sufficiently high throughout the experimental period to nodulate emerging clover in subsequent years.

ADDITIONAL KEY WORDS: Trifolium subterraneum L., Cynodon dactylon L., nitrogen fixation, mined land productivity.

Introduction

Reclamation of lignite mine spoils has become increasingly important in Texas, since it has been estimated that approximately one million acres of land will be disturbed by the mining of near-

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[3] Publication in this proceedings does not preclude authors publishing their manuscripts, whole or in part, in other publication outlets.

surface lignite deposits (Clarke and Baen, 1980). Coastal bermudagrass (Cynodon dactylon L.) monocultures are commonly used in reclamation of mine spoils in Texas, but the establishment and maintenance of this warm-season species requires large inputs of nitrogen fertilizer. Coastal bermudagrass grows from June through October, then becomes dormant during the winter and spring. The successful utilization of clovers in mine spoil reclamation has been reported in Texas as well as other regions (Hons et al., 1980; Jefferies et al., 1981). Their ability to meet their own nitrogen demands through the fixation of atmospheric nitrogen in a symbiotic association with Rhizobium, combined with the possibility of supplying nitrogen to neighboring nonleguminous species or subsequent crops, demonstrates their potential benefits in establishing a successful mine reclamation program. Major benefit could result from a reduction of nitrogen fertilizers.

Subterranean clover (Trifolium subterraneum L.), a cool-season, reseeding annual legume, has not been widely used in reclamation practices in Texas. This clover emerges in late November and actively grows from January through May. Subterranean clover will then set seed in May and is no longer present until the seed germinates the next season. Several characteristics which make this clover an excellent choice for revegetation of spoil include: dense ground coverage facilitating erosion and weed control, relatively easy establishment, tolerance of acidic soils, and dependable reseeding under continuous, close grazing (Evers, 1979; Evers and Shipe, 1980; Knight et al., 1982). Subterranean clover can be seeded into existing coastal bermudagrass sods, with the grass actively growing during the summer months and becoming dormant in the winter and spring when the clover emerges and establishes.

The presence of an effective nitrogen-fixing bacterial population (Rhizobium) is necessary for the successful establishment and maintenance of clovers in a reclamation program. The effectiveness of Rhizobium and its beneficial association with clovers can be influenced by many factors including pH, temperature, moisture, nutrient availability, and other physical, chemical, and biological parameters (Lowendorf, 1980). The failure of establishment and/or persistence of subterranean clover is frequently due to the lack of an effective population of Rhizobium (Knight et al., 1982). Specific strains of Rhizobium leguminosarum biovar trifolii are required for effective nodulation of subterranean clover and subsequent efficient nitrogen fixation. A major problem in the establishment of an effective Rhizobium leguminosarum biovar trifolii-subterranean clover relationship is the possible presence of ineffective indigenous strains of Rhizobium in the mine spoil. Indigenous strains have been found that will nodulate subterranean clover, but they often demonstrated little or no nitrogen-fixing ability in association with the clover (Holland, 1970; Mott, 1984; Mott and Zuberer, 1983).

Our major objectives in this study were to determine the effects of fertilization and inoculation with Rhizobium leguminosarum biovar trifolii on the establishment and growth of subterranean clover, to assess the effect of clover on performance of coastal bermudagrass, and to evaluate the survival of Rhizobium in mine spoil.

Materials and Methods

A field experiment was established in October, 1986, at the Big Brown Mine near Fairfield, Texas. Field plots of subterranean clover were established in a six-month-old coastal bermudagrass sod. 'Mt. Barker' subterranean clover was planted by hand broadcasting seed at a rate of 33.6 kg pure live seed (PLS) ha^{-1}, then raking the seed into the spoil. The seeds were inoculated with a commercial, mixed-strain inoculant (Nitragin Co.) prior to planting. Uninoculated clover plots and control plots containing only coastal bermudagrass were also established. Low numbers (0 to 10^2 rhizobia g $soil^{-1}$) of native rhizobia effective in association with subterranean clover were present in the mine spoil prior to plot establishment. Three fertilization treatments were also incorporated into the study. Plots were fertilized with 336 kg ha^{-1} of 17-17-17 or 0-17-17, corresponding to application rates of 57, 25, and 47 kg ha^{-1} of nitrogen, phosphorus, and potassium, respectively. Nonfertilized plots were also maintained. Individual plots were 2 m by 2 m and four replications of each treatment were included.

Clover plots were clipped twice in the spring of 1987 and 1988 to a height of 7.5 cm using a rear-bagging Snapper Hi-Vac mower. Coastal bermudagrass was not actively growing during this period. During the summer and fall of 1987 and 1988, coastal bermudagrass was cut to a height of 7.5 cm using the same mower. Subterranean clover was not present in the plots during this period. All plant samples were oven-dried at 70C for 4-5 days, and yield was determined on a dry weight basis. Clover and coastal bermudagrass samples were ground to pass through a 20 mesh screen and digested using the micro-Kjeldahl method (Nelson and Sommers, 1973). Total nitrogen and phosphorus were determined using a Technicon Autoanalyzer II Continuous Flow System (Technicon, 1977). Ground coverage (percentage area covered) was visually estimated periodically throughout the experimental period using a grid containing 100 squares measuring 20 cm by 20 cm over the entire plot (Brown, 1954).

Throughout the two years of the experiment, spoil samples were collected to a depth of 15 cm using a 2.5 cm diameter soil core probe. Samples were stored in sterile Ziploc bags, and processed within 48 hours to determine the numbers of Rhizobium leguminosarum biovar trifolii in the spoil in the presence or absence of the host species. Populations of Rhizobium were estimated using a most probable number (MPN) plant infection technique (Mott, 1984; Weaver and Frederick, 1972). Serial dilutions of spoil material were inoculated into plastic growth pouches containing subterranean clover. After 4 to 5 weeks, roots were examined for the presence or absence of nodules. The MPN of Rhizobium capable of infecting subterranean clover was determined using a statistical table (Brockwell, 1963 in Vincent, 1970). The effectiveness of nodulated plants from the growth pouches was determined using the acetylene reduction (AR) assay (Hardy et al., 1968; Mott, 1984). This assay estimates nitrogen-fixing capacity by measuring ethylene production during incubation of plants with acetylene to measure nitrogenase activity. The MPN of effective Rhizobium was based on results of the AR assay. All statistical analyses in this study were performed using the Statistical Analysis System (SAS) (Helwig and Council, 1979).

Table 1. EFFECT OF INOCULATION AND FERTILIZATION ON SUBTERRANEAN CLOVER BIOMASS PRODUCTION FROM LIGNITE SPOIL PLOTS

	Harvest Date					
Treatment	3/87	4/87	Total-87	3/88	4/88	Total-88
			kg ha^{-1}			
Inoc - No Fert	98b*	346a	444c	1095b	1274a	2369c
Unin - No Fert	0b	222a	222c	976b	2052a	3028bc
Inoc - 0-17-17	1542a	914a	2456ab	1567ab	2116a	3683abc
Unin - 0-17-17	226b	679a	906bc	1592ab	2044a	3637abc
Inoc - 17-17-17	1742a	1060a	2802a	2471a	2109a	4580a
Unin - 17-17-17	410b	1114a	1524abc	1943ab	1988a	3931ab

*Means in each column followed by the same letter are not significantly different at p=.05 by Tukey's studentized range test.

Results and Discussion

Dry matter yields of subterranean clover in 1987 and 1988 are summarized in Table 1. At the first harvest in 1987, yields were greatest in the inoculated, fertilized plots. Yields were not significantly increased by the addition of N. Lowest yields were found in the inoculated and uninoculated plots where no fertilizer was added. At the second clipping, yields were not significantly different between any treatment but tended to be greater in all plots with added P and K. Total yields for 1987 were greater in the inoculated plots across all fertilizer treatments. Inoculated plots with P and K added had the highest yields, and addition of N did not significantly increase yields. In 1988, clover yields were more influenced by fertilizer addition than inoculation. At the first harvest, yields tended to be greater in the plots where N, P and K were added, although these yields were not significantly greater than those from plots receiving only P and K. Yields were not significantly different between any treatments at the second clipping. Total yields in 1988 tended to be greater in all plots receiving P and K. Approximately 900 kg ha^{-1} of extra dry matter resulted from inoculation with appropriate rhizobia in lieu of applying fertilizer N in 1987. Early season forage production was greatly improved through the use of inoculant on fertilized plots, with an average additional production of 1300 kg ha^{-1} (300% increase) of dry matter in the first clipping in 1987, even though low numbers of indigenous rhizobia were present in plots at the time of establishment. Average total yields in 1988 were nearly twice those obtained in 1987, probably due to the denser plant cover obtained with natural reseeding of the subterranean clover. By the end of the first growing season, ground coverage of all plots ranged from 80 to 95% of the plot area, and coverage achieved the same level in 1988 (data not shown).

Table 2 summarizes the dry matter production of coastal bermudagrass in 1987 and 1988. In 1987, no significant differences were found in yields from all treatments at the first clipping.

Table 2. EFFECT OF PREVIOUS CLOVER CROP AND FERTILIZATION ON COASTAL BERMUDAGRASS BIOMASS PRODUCTION FROM LIGNITE SPOIL PLOTS

	Harvest Date					
Treatment	6/87	10/87	Total-87	7/88	9/88	Total-88
			kg ha^{-1}			
Inoc - No Fert	1847a*	1454ab	3301a	2242bc	1544abc	3786abc
Unin - No Fert	1532a	1340ab	2872a	1872bc	1357abc	3229bc
Cont - No Fert	2377a	817b	3192a	1503c	986c	2489c
Inoc - 0-17-17	2148a	1623ab	3771a	3001ab	1604ab	4605ab
Unin - 0-17-17	1588a	1594ab	3181a	2646ab	1468abc	4114ab
Cont - 0-17-17	2466a	1089ab	3556a	1260c	1191abc	2451c
Inoc - 17-17-17	2484a	1851a	4336a	3468a	1746a	5214a
Unin - 17-17-17	2530a	1554ab	4084a	3373a	1579ab	4952a
Cont - 17-17-17	3059a	1156ab	4215a	2685ab	1158bc	3842abc

*Means in each column followed by the same letter are not significantly different at p=.05 by Tukey's studentized range test.

Yields tended to be higher at all fertilizer levels in the control plots where no clover had been grown. This may have been due to greater nutrient and moisture availability due to the absence of the clover. At the second clipping, yields tended to be lower in the control plots across all fertilizer treatments, with bermudagrass yields approximately 50% greater in the plots where clover had previously grown as compared to control plots at any given fertilizer level. Total dry matter production in 1987 was not significantly different among treatments. However, fertilized plots showed a trend toward greater yields, with 300 to 400 kg ha^{-1} of extra dry matter produced in plots fertilized with P and K as compared to unfertilized plots, while addition of N resulted in an additional increase of approximately 700 kg ha^{-1} of dry matter production. At the first clipping in 1988, bermudagrass yields tended to be greater on the clover plots where at least P and K were added, and lowest in the control plots (grass only) with no added N. Yields tended to be greater in the plots where clover had previously been present regardless of fertilizer treatment at the second clipping. Total dry matter production in 1988 tended to be greater in the plots fertilized with N, P and K. Yields tended to be lower in the control plots where no N was added. When no fertilizer was used, approximately 1000 kg ha^{-1} of additional dry matter were produced in the plots where clover had been grown as compared to control plots. When N, P and K were added, yield increases were about 1200 kg ha^{-1}. When only P and K were applied to the plots, an average of 1900 kg ha^{-1} of additional dry matter was produced from bermudagrass plots where clover had been present prior to the bermudagrass growing season. The use of clover with coastal bermudagrass presumably increased dry matter production through the transfer of N from the mineralization of the legume.

Table 3. EFFECT OF INOCULATION AND FERTILIZATION ON NITROGEN AND PHOSPHORUS HARVESTED IN SUBTERRANEAN CLOVER FROM LIGNITE SPOIL PLOTS

	Total Nitrogen		Total Phosphorus	
Treatment	1987	1988	1987	1988
		kg ha^{-1}		
Inoc - No Fert	13.1c*	50.5b	0.63c	2.74b
Unin - No Fert	6.4c	78.5ab	0.32c	5.10ab
Inoc - 0-17-17	84.4a	101.1ab	5.07a	6.29ab
Unin - 0-17-17	27.8bc	94.3ab	1.74bc	6.83a
Inoc - 17-17-17	91.7a	118.6a	5.87a	7.91a
Unin - 17-17-17	42.6b	98.5ab	2.78b	7.42a

*Means in each column followed by the same letter are not significantly different at p=.05 by Tukey's studentized range test.

Total nitrogen and phosphorus harvested in subterranean clover in 1987 were significantly greater in the inoculated plots receiving P and K (Table 3). About 60 kg ha^{-1} of N was gained through inoculation instead of adding fertilizer N, which would provide a substantial savings in fertilizer costs. An approximate 100% increase in total P harvested resulted from inoculation when P and K were applied. The response to inoculation was not observed in 1988, where total N and P yields were similar for both inoculated and uninoculated treatments when P and K were added (Table 3). The indigenous rhizobia were presumably able to form an effective relationship with the clover by the second year or inoculant rhizobia had been transported to the uninoculated plots. Table 4 shows the total N and P harvested in coastal bermudagrass in 1987 and 1988. In 1987, N and P production tended to be greater in all plots fertilized with N, P and K, and the inoculated plots with P and K added. The lower yields of the other treatments were probably due to the need for additional N. In 1988, total N and P in coastal bermudagrass tended to be greater in the plots where clover had previously grown at each fertilizer level. Increased uptake of N and P by the coastal bermudagrass was found when subterranean clover was seeded into the grass, with an approximate 100% increase in total N and P in the grass harvested from the clover plots as compared to the control plots at any fertilizer level.

The most probable numbers of Rhizobium in the lignite spoil plots throughout the experimental period are shown in Table 5. At the end of the first growing season (5/87), inoculated as well as uninoculated plots contained 10^4 to 10^5 rhizobia g $soil^{-1}$. Although numbers were similar in inoculated and uninoculated plots and the rhizobia in the uninoculated plots were shown to be effective in association with subterranean clover (data not shown), an efficient symbiotic relationship was not formed early by the rhizobia with the clover, as indicated by the yield data previously discussed. There were approximately 10^3 rhizobia g $soil^{-1}$ in all clover plots at the time of clover

Table 4. EFFECT OF PREVIOUS CLOVER CROP AND FERTILIZATION ON NITROGEN AND PHOSPHORUS HARVESTED IN COASTAL BERMUDAGRASS FROM LIGNITE SPOIL PLOTS

	Total Nitrogen		Total Phosphorus	
Treatment	1987	1988	1987	1988
		kg ha^{-1}		
Inoc - No Fert	27.4a*	34.4bcd	4.83a	5.85bcd
Unin - No Fert	21.8a	29.0cde	3.84a	5.38cd
Cont - No Fert	25.8a	19.6e	3.79a	3.14f
Inoc - 0-17-17	33.8a	42.8ab	6.54a	7.63ab
Unin - 0-17-17	27.2a	40.8abc	4.51a	6.86abc
Cont - 0-17-17	24.2a	17.8e	3.96a	3.47ef
Inoc - 17-17-17	39.9a	51.8a	7.17a	8.31a
Unin - 17-17-17	34.6a	48.3a	6.36a	8.26a
Cont - 17-17-17	29.7a	25.1de	5.02a	5.00de

*Means in each column followed by the same letter are not significantly different at p=.05 by Tukey's studentized range test.

Table 5. EFFECT OF INOCULATION AND FERTILIZATION ON MOST PROBABLE NUMBERS OF RHIZOBIUM IN LIGNITE SPOIL PLOTS

	Sampling Date					
Treatment	5/87	10/87	1/88	5/88	7/88	11/88
			log # g soil^{-1}			
Inoc - No Fert	4.39a*	3.01a	3.06ab	4.97ab	4.53ab	4.05abc
Unin - No Fert	5.03a	3.49a	3.24ab	5.34a	4.83a	4.52abc
Cont - No Fert	1.31b	0.63c	0.65c	2.56c	2.83bc	2.60abc
Inoc - 0-17-17	5.24a	2.96a	3.77a	5.52a	5.15a	4.79ab
Unin - 0-17-17	5.31a	3.33a	3.68a	6.21a	5.78a	4.78ab
Cont - 0-17-17	2.03b	1.08bc	1.86abc	2.91c	2.45c	1.86c
Inoc - 17-17-17	4.97a	2.56ab	3.65a	5.62a	5.25a	4.98a
Unin - 17-17-17	5.46a	3.44a	3.81a	5.87a	4.90a	4.67ab
Cont - 17-17-17	1.67b	0.58c	1.40bc	3.05bc	2.76bc	2.25bc

*Means in each column followed by the same letter are not significantly different at p=.05 by Tukey's studentized range test.

emergence in the second season (10/87), whereas rhizobia were virtually undetectable in the control (no clover) plots. Numbers of Rhizobium at the end of the second year (5/88) were similar to those found at the end of the first growing season. Populations declined somewhat throughout the rest of 1988. There were approximately 10^4 rhizobia g soil^{-1} at the time of clover emergence at the beginning of the third year. The fluctuations in numbers of rhizobia were influenced by the presence or absence of the host species, with numbers decreasing in the summer months when subterranean clover is absent, and increasing again each year after clover emergence.

Summary

Inoculation with the proper strains of Rhizobium resulted in increased production of subterranean clover (75%), along with increased total N and P (100%), in the first clover growing season, even though low numbers of effective rhizobia were present in the mine spoil. Fertilization with P and K increased growth of clover in comparison with nonfertilized plots, while addition of N did not increase yields on fertilized plots. Coastal bermudagrass production was enhanced (75%) through the presence of subterranean clover prior to the bermudagrass growing season, probably due to the availability of additional N from the clover. Finally, sufficient numbers of Rhizobium were able to survive in the mine spoil, even when the host species was absent, to nodulate and form an effective symbiotic relationship with emerging subterranean clover in subsequent years.

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GRAIN SORGHUM AS A TEST CROP TO RECLAIM PRIME FARMLAND DISTURBED FOR COAL MINING[1]

by

R.I Barnhisel and J.L. Powell[2]

ABSTRACT Data are presented to summarize experiments having the following objectives: 1) Determine the yield potential of selected grain sorghum cultivars. 2) Determine the effect of soil depth and the previous cropping history on grain sorghum yield. 3) Determine the effect of liming the subsoil prior to topsoil replacement on grain sorghum yield.

In general, grain sorghum is a good test crop for the evaluation of reclamation success (i.e., productivity) of prime farmland, however, wide variations occur between varieties. Grain sorghum responded to increased soil depth covering the cast overburden, with the greatest yield increase occurring between the 20 and 60 cm depth treatments and a lesser yield response between 60 and 100 cm treatments. The previous cropping history affected grain sorghum yields. Plots that had been in alfalfa and tall fescue during the initial five years of this study outyielded those that were in a corn-wheat-soybean rotation. The application of lime to the acidic subsoil resulted in a significant yield increase.

ADDITIONAL KEY WORDS: soil depth, subsoil liming, bond release, target yield.

INTRODUCTION

The Surface Mining Control and Reclamation Act (SMCRA) of 1977 mandates that the coal operator demonstrate the return of surface mined land to its original productivity. Several test crops may be used in various states to meet the performance standards of current regulations. In Kentucky, corn (*Zea mays* L.) must be grown one of the three years required for demonstrating the return of productivity, while various crops may be utilized the other two years. Wheat (Triticum aestivum L.) has been successfully grown on prime and non-prime sites, including cast-overburden, and yields are affected by cultivar selection and depth of replaced soil (Barnhisel et al., 1988a). In that study, three soil depths were used: 25, 50, and 75 cm in a randomized 3 x 3 factorial experimental design. A significant yield response to soil depth was found between the 25 and 50 cm treatments but not between 50 and 75 cm.

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Studies to determine the minimum depth of soil necessary to achieve a post-mining productivity equal to pre-mining productivity has resulted in numerous publications (Deane, 1977; Farmer et al., 1974; Nielsen and Miller, 1980; Power, 1978; Power et al., 1981; Russell, 1977; Sandoval and Gould, 1978; Sindelar et al., 1973; Taylor and Gardner, 1963; and Zimmerman and Kardos, 1961). The crop being grown strongly influences the topsoil depth requirement, as do the chemical, physical, and mineralogical nature of the spoil material underlying the topsoil. Where spoil properties do not restrict root growth, less topsoil is needed to provide a rooting media for optimum crop production (Grandt, 1978 and Barnhisel et al., 1988a,b).

The rational for using grain sorghum as a test crop for evaluating various treatments in both non-prime and prime farmland reclamation projects is because it has several traits that reduce the risks of crop failure. It withstands stress drought better than corn or soybeans (Glycine max (L.) Merr.) by becoming semi-dormant, and its more fibrous root system is more efficient in extracting soil moisture. Pollination of sorghum is not as severely affected by hot temperatures as that of corn. When moisture and nutrients are adequate, grain sorghum produces extra tillers and seed heads, whereas during drought only the primary tiller will produce a seed head. Grain sorghum will also withstand excessive moisture conditions better than either corn or soybeans.

Coal companies are searching for ways to reduce costs and minimize risk, yet meet performance standards of SMCRA. To obtain information needed to make recommendations about the use of grain sorghum in mine land reclamation, field research projects were established with the following objectives: 1) Determine the yield potential of selected grain sorghum cultivars. 2) Determine the effect of soil depth and the previous cropping history on grain sorghum yield. 3) Determine the effect of liming the subsoil prior to topsoil replacement on grain sorghum yield.

METHODS AND MATERIALS

The two studies reported here were conducted on different surface mines operated by Peabody Coal Company. These sites (Alston and River Queen) have been used in earlier-reported studies, hence only brief details on plot construction and spoil and soil characteristics will be given here. At both sites, two soils were replaced as a mixture. The soil mixture consisted of the Sadler (Glossic Fragiudalf, fine-silty, mixed, mesic) and the Belknap (Aeric Fluvaquent, coarse-silty, mixed, acid, mesic). The Ap horizon or topsoil was segregated from the B or subsoil horizon for each soil in both experiments.

Lime was applied at the Alston and River Queen sites as calcitic limestone at 11 Mg ha^{-1} and 15 Mg ha^{-1}, respectively. This lime was applied following topsoil replacement and prior to the establishment of any experiments. P and K fertilizers were applied at different times throughout the experimental period when needed as 0-46-0 and 0-0-60, respectively and the rates used were according to soil test recommendations published in AGR-1.[3] Nitrogen was also applied in the form of ammonium nitrate as a split application of 150 kg N ha^{-1} at planting and 50 kg N ha^{-1} as a side-dressing about 40 days after emergence.

The grain sorghum was seeded in 76 cm rows at a rate of 8 kg ha^{-1} using a no-till drill. Grain was harvested using a plot combine, weighed to the nearest 0.1 kg, and yields were corrected to a standard 15% moisture. Following statistical analyses, data were rounded to the nearest 5 kg ha^{-1}.

Effect of Previous Crop Rotation and Subsoil Liming

The Alston Surface Mine was the location of this experiment. Although details of plot construction are given elsewhere (Barnhisel, 1983 and Barnhisel et al., 1988b), briefly, the six treatments consisted of three soil depths (given below) and two lime rates (0 and 45 Mg ha^{-1}). For two of the soil depth treatments, lime was incorporated into the upper 10-15 cm of the acidic subsoil prior to replacement of the topsoil. The subsoil depths were 40 and 80 cm. For the third treatment, the lime was incorporated into spoil overburden materials prior to its being topsoiled. Both the subsoil and the 20 cm of topsoil which was applied to the entire area were replaced with scraper pans.

The sequence of crops grown on this site is given in Table 1. Changes in soil bulk density values and alfalfa yields were reported in an earlier publication (Barnhisel et al., 1988b). Funks G1602 grain sorghum variety was seeded in the first week of May.

Effect of Grain Sorghum Cultivars

The second experiment on River Queen was adjacent to the area on which corn hybrids were evaluated and a more detailed description of plot construction is given elsewhere (Powell et al., 1988). The soil was replaced with scraper pans in which approximately 80 cm of subsoil was deposited and, following leveling with a dozer, 20 cm of topsoil was replaced.

Both the number and selection of grain sorghum varieties were changed some each year, based upon availability of space and entries provided by cooperating seed companies for this cultivar testing study. In all cases, five replications were used each year and plots consisted of 2 rows, 76 cm apart and 13 meters long. However, plots were trimmed to 11 meters prior to being harvested with the plot combine.

RESULTS AND DISCUSSIONS

In Kentucky, the USDA-SCS has not established target yields for grain sorghum for the prime farmland soils that are likely to be disturbed by surface mining. However, they have estimated the yield potential of corn on the two soils used in these experiments. Corn yields would be expected to be about 6600 and 6900 kg ha^{-1} for the Sadler and Belknap soils, respectively. Based on the relative proportions of the areas that the

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[3] AGR-1 Lime and Fertilizer Recommendations, Kentucky Agricultural Experiment Station, University of Kentucky, Lexington, KY.

Table 1. Crop rotations utilized at the Alston Surface Mine Site prior to the grain sorghum study in 1986.

Year	Plot Subtreatments* 1	2	3	4
1978	Alfalfa	Corn	Soybeans	T. Fescue
1980	Alfalfa	Soybeans	Corn	T. Fescue
1981	Alfalfa	Corn	Wheat/Soybeans	T. Fescue
1982	Alfalfa	Wheat/Soybeans	Corn	T. Fescue
1983	Alfalfa	Corn	Wheat	T. Fescue
1984	Corn	Corn	Corn	Corn
1985	Corn	Corn	Corn	Corn
1986	Gr. Sorghum	Gr. Sorghum	Gr. Sorghum	Gr. Sorghum

* Plot Subtreatments will be used to identify crop rotations in subsequent grain sorghum yield tables.

Sadler and Belknap comprise, the pro-rated yield potential for corn for these studies would be about 6700 kg ha^{-1}. Over the past 10 years, the state-wide average yield difference between corn and grain sorghum is 1480 kg ha^{-1}. Hence, the target yield of 5220 kg ha^{-1} was estimated to be for the restored mixed soil. According to SMCRA regulations, values are considered equal if they fall within the LSD$_{(.10)}$ statistical variation limit. The LSD$_{(.10)}$ is subtracted from each year's data, hence the target yield is not necessarily constant. In addition, a yield reduction may be allowed due to damage from adverse weather conditions, insects, or pests, including grazing animals. However, in Kentucky, such a reduction cannot exceed 10%.

Effect of Cultivar Selection on Grain Soybean Yield

Grain sorghum yields from the variety experiment are summarized in Table 2. Based on the discussion presented earlier, the target for the restored soil mixture equalled 4245, 4240, 4185, and 4410 kg ha^{-1} for 1985, 1986, 1987, and 1988, respectively. In 1985, 9 cultivars exceeded the target yield value, whereas in 1986, 1987, and 1988, only 1, 4, and 2 varieties met the target yield goals in those respective years.

Only one of the entries screened in this experiment exceeded the target yield more than one year out of four. Unfortunately, space did not allow testing all 27 varieties for the entire 4-year period, and some cultivars were added while others were dropped. The growing seasons of both 1987 and 1988 were moisture deficient, but at different times. In 1987, the drought occurred in late July and early August, whereas in 1988, it occurred in late May and June. The average yields for those years were 3345 and 3250 kg ha^{-1}, respectively. Although there are differences in maturity within the cultivars tested, this did not appear to influence yield either of the two drought years. The two highest yielding varieties in 1988

Table 2. Grain sorghum yield as a function of cultivar.

Brand - Hybrid	Maturity Group	Yield* 1985	1986	1987	1988
		$kg\ ha^{-1}$			
Northrup King - 2778	3	5460	4140	4680	----
Taylor Evans - Y101G	3	5160	3240	3840	3000
Funks - G1602	3	4800	3360	----	----
Funks - G522DR	3	4620	2820	2640	3420
Funks - RA787	3	----	----	----	3840
Taylor Evans - Dinero	3	4560	2940	2700	2760
Taylor Evans - Dinero E	3	----	2820	----	----
Northrup King - 2779	3	----	----	3240	2640
Northrup King - 2660	3	4320	3540	2100	3540
Northrup King - S9740Y	3	----	----	----	3600
Northrup King - 734G	3	----	----	----	2220
Asgrow - Topaz	3	4260	2460	3360	3000
Funks - G1711	4	4260	3720	3420	3900
Taylor Evans - Y45G	1	4140	4320	----	----
Northrup King - 2244	2	4020	----	----	----
DeKalb - DK42Y	2	3840	----	3420	2700
DeKalb - M565	2	----	----	2580	3360
So. States - SS174	3	3540	3900	----	----
Pioneer - 8333	3	3540	4020	4380	2640
Pioneer - 8515	3	3540	4020	4440	1860
Pioneer - 8226	3	----	----	3300	2580
Taylor Evans - Y77	2	3480	----	----	----
Asgrow - GS 712	4	----	4080	3120	5100
Taylor Evans - Y75	2	----	2820	2860	5460
Asgrow - Mustang	3	----	2840	4800	2820
Garst - 5511	3	----	----	----	3120
Garst - 5521	3	----	----	----	3420
$LSD_{(.10)}$		975	980	1035	810

* Cultivars listed according to 1985 yield values. Dashed lines indicate variety was not planted.

were of maturity groups 2 and 4, respectively, whereas in 1987, the highest two varieties were classified within maturity group 3.

In 1987, mechanical problems with the plot combine caused a delay in harvest and excessive bird damage occurred. In general, all varieties had losses: some were estimated to be as large as 25%. If the maximum yield correction due to pests allowed by SCMRA is made, the target yield would become 3765 kg ha^{-1}, however, only one additional hybrid would be added to the list meeting the target yield value for Phase III bond release. For 1988, even if maximum corrections were to be allowed due to the early drought, the number of cultivars meeting the target yield level would not have been different.

Effects of Previous Crop Rotation and Subsoil Liming

The yield data for grain sorghum at the Alston Surface Mine, are given in Table 3. Many of the treatments exceeded the target yield for Phase III bond release, estimated to be 4620 kg ha^{-1}.

For the prime farmland treatment having a limed subsoil (100 cm L), three of the four plot subtreatments resulting from the various crop rotations met the target yield level. Similarly, three of the four subtreatments of the limed subsoil, non-prime farmland (60 cm L) also exceeded the target of 4620 kg ha^{-1} for prime farmland. None of the plots in which only topsoil was replaced directly over spoil met the target yield for prime farmland.

Significant differences were associated with the previous sequence of crops grown on the site, soil depth, and liming the upper 10-15 cm of the subsoil prior to replacement of the topsoil. Grain sorghum yields were more nearly consistent with the hypothesis that yields from deeper soils and/or subsoil liming would be expected to be greater than those from shallow and/or acidic subsoils. Such a yield response to neither soil depth nor subsoil liming was not found for alfalfa on these same plots during 1979 - 1983 (Barnhisel et al., 1988b). Grain sorghum yields from those treatments which had been in either alfalfa or tall fescue exceeded the yields from the corn-wheat-soybean rotation in every case except one (60 cm, limed treatment). This effect was still prevalent even though the entire area had been planted to corn for two intervening years.

The lime applied to the subsoil resulted in a numerically greater yield in all cases and, in

Table 3. Grain sorghum yield as a function of soil depth, previous crop, and subsoil lime treatment.

Soil Depth	Plot Subtreatment 1	2	3	4	$LSD_{(.10)}$
cm	kg ha^{-1}				
100 NL*	5175	4165	3900	4100	605
100 L	6250	4500	4840	6520	680
60 NL	3830	4225	4435	4165	455
60 L	4370	4975	5240	5375	710
20 NL	2755	875	1680	3160	610
20 L	3225	2555	2220	2620	365
$LSD_{(.10)}$	580	570	795	590	---

* Subsoil or spoil not limed (NL); subsoil or spoil limed (L).

six of the eight cases, a significantly greater yield. The exceptions were subtreatment 1 on the 60 cm soil depth and subtreatment 2 on the 100 cm soil depth. Liming the spoil materials did not produce consistent results, since in three cases the lime treatment increased the grain sorghum yield, and in one case liming decreased yield, but not significantly.

Of the eight possible comparisons between similar subsoil lime treatments with different depths, i.e., 100 cm versus 60 cm, only three differed significantly. Two of these significant differences were from the "alfalfa" subplot treatment and one was from the area that was in tall fescue from 1979 to 1983. For the other 5 comparisons, the shallower soil depth resulted in a numerically greater yield, but none was significantly greater.

In comparisons between similarly limed or non-limed treatments in which only 20 cm of topsoil was replaced versus either 40 or 80 cm of subsoil, all cases significantly favored the presence of replaced subsoil. Furthermore, in all 16 cases these differences were significant.

CONCLUSIONS

1. The use of grain sorghum as a test crop to determine the return of soil productivity following reconstruction of prime farmland is very promising. It is subject to drought stress, but is less affected than corn.

2. There were significant differences among varieties, and the order with respect to yield over time was different. Some varieties were near the top both years, others near the bottom, whereas others changed rankings when subjected to drought stress. Additional testing is continuing in order to assist coal operators in selecting varieties of grain sorghum.

3. The previous cropping sequence, soil depth, and subsoil liming significantly affected grain sorghum yields. Yields were highest following either alfalfa or tall fescue. The deeper the soil, the higher the yield. Liming the subsoil prior to replacement of the topsoil increased grain sorghum yields.

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Woody Plant Revegetation & Succession

Session Chairman: A.J. Kennedy

DETERMINING OPTIMAL INITIAL STOCKING DENSITIES DURING MINE RECLAMATION[1]

by

Peter R. Guy and J. Cam Bateman[2]

Abstract. The purpose of this study was to describe ways of determining what planting densities should be used on reclaimed land. Data were collected to rate various species on their 'aggressiveness' or their ability to colonize new areas. Recommendations were made on what planting densities would lead to the development of three different plant communities on reclaimed tar sands in northern Alberta.

Introduction

The "Guidelines for the Reclamation of Land in Alberta" (Alberta Land Conservation and Reclamation Council, 1977) state:

> "where the prescribed post-disturbance land use is the establishment of permanent vegetation suitable for wildlife habitat, the operator is responsible for the establishment of various species and numbers of trees, grasses, forbs and shrubs of a density and composition which will provide food and cover for wildlife, consistent with the ecological zone of the region and satisfactory to the Approving Authority".

Because the target densities and species composition of wildlife habitat on reclaimed areas have to be consistent with the ecological zone of the region, routine field work in the areas surrounding the area to be reclaimed provides this information. What is less simple to determine is what planting densities should be used to ensure that the target densities are achieved.

Some Concepts of Reclonization

We believed that the target densities could be met in two ways by (1) establishing a few plants of each species and allowing natural succession, regeneration and immigration to take place; or (2) by establishing many plants of each species and allowing natural mortality and competition to take place.

These were termed the primary innoculum and the secondary innoculum, respectively the terms having been derived from the ecological concepts of primary and secondary succession. Primary succession is defined as "development which begins on an area that has not been previously occupied by a community", and secondary succession as "community development proceeding in an area from which a community was removed" (Odum 1971). Secondary succession is more rapid than primary succession because some organisms or their disseminules are already present, and previously occupied lands are more receptive to community development than sterile areas.

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[1] Paper presented at the conference Reclamation, A Global Perspective, held in Calgary, Alberta, Canada August 27-31, 1989.

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The species densities established in a secondary innoculum would be close to those found in climax communities; the species densities established in a primary innoculum are much less but over time these will result in densities equal to those in climax communities i.e. will succeed toward the density of a secondary innoculum. The major difference in these two alternatives is the time frame and this has important ramifications to the approach industry might adopt when initiating a reclamation project.

The time taken for a community to progress through secondary succession and the stocking densities of the major species involved are well documented (e.g. Odum 1971). However, the time taken and the densities of plants involved in primary succession are not well documented, making it very difficult to formulate stocking density recommendations. The time factor is dependent both on the silvical characteristics of the individual species involved and on the edaphic conditions. The ideas that follow are based primarily on the silvical characteristics because it is believed that ultimately these will be the major factors controlling community development on reclaimed sites throughout Alberta.

Species Aggressiveness

To meet the objective of this study information on silvical characteristics that determine the "aggressiveness" of a species was collected. The rate of spread of a species is determined by characteristics such as: (1) the primary means of reproduction, (2) reproductive age, (3) seed viability, (4) seedbed requirements, (5) seed dispersal distance, (6) seedling survival rates, (7) degree of vegetative reproduction, (8) reaction to competition, (9) seed crop periodicity and (10) amount of seed produced. Stocking densities should be based on these characteristics: the premise being that over a given period, aggressive species will require lower stocking densities initially than less aggressive species. However, the aggressiveness of a species also depends on the site conditions encountered and the subsequent management procedures provided. For example, because suckering in aspen is dependent upon temperature and light, planting densities need be considerably less on south facing slopes than on north facing slopes because of the increased insolation. Removal of apical dominance has also been shown to be an effective means of increasing densities in aspen stands (Schier, Jones and Winokur 1985). This causes profuse and vigorous suckering, increasing aspen's aggressiveness. Where these management practices can be implemented, the initial stocking densities can be reduced.

The dependence of lodgepole pine on fire in natural situations is a classic example of factors affecting the regenerative potential of a species. Lodgepole pine is most aggressive on sites where repeated fires occur because it produces seed at an early age, and the amount of seed available for regeneration increases with time because the seed is held in serotinous cones. In formalizing this concept, Rowe and Scotter (1973) rated various coniferous species on their regenerative ability following fire. Jack pine was given the highest index because it stores a lot of seeds, it produces seeds when young, it has frost-hardy, rapidly growing seedlings and it grows well in full sunlight. On the other hand, white spruce was rated less highly, because it does not produce seed when young, it does not store its seeds, it is not frost-hardy and it prefers to grow in partially shaded sites. Therefore it is logical to assume that a higher initial stocking density of white spruce would be required to provide the same density as jack pine at a given age following a fire.

Following the lead of Rowe and

Scotter (1973), data for various species were compiled from the literature to determine how quickly a species could spread from seed alone. The age of earliest and abundant seed production, the number, periodicity and quality of seeds produced, dispersal distance, and viable seed to established seedling ratio are given (Table 1). Also included is the average seedling survival of each species at the Suncor site in northern Alberta.

Using these data, the expected rate of spread of these species by seed can be calculated. An example is given below for paper birch.

Assume: 1 paper birch planted in 1985 into an area with an organic seedbed

First seed produced: 1985 + 15 years = 2000 and every two years thereafter
Viable seed: 150 000 seeds produced x 20% viable = 30 000 viable seeds
Seedlings: 30 000 viable seeds ÷ 400 seeds/seedling on organic seedbeds = 75 seedlings
Seedling Survival: 75 seedlings x 20% survival = 15 established seedlings

These calculations show that one paper birch planted in 1985 will give rise to roughly 15 established seedlings in 2001, 2003, 2005 ... etc.

The number of established seedlings on mineral soil is increased by up to 300 in 2001 and every two years following (Table 1). The differences for seedling establishment between mineral soil and organic seedbeds for the other species are even more dramatic.

The same exercise for white spruce indicates approximately 14 seedlings will become established on organic seedbeds and up to 600 seedlings on mineral soil in the year 2006 and every three years thereafter.

The high rodent populations which frequently occur on reclaimed sites and the sod-forming nature of many herbaceous species used in reclamation, such as red top and bluegrasses, will limit reproduction from seed. However, some species have been reproduced successfully from seed on reclaimed areas. At the Victory Mine near Wabamun, Alberta, Manitoba maple, green ash and caragana have grown from seed in a plantation established in 1958 (Monenco Limited 1982). All three of these species are precocious seed producers and produce relatively large seeds capable of germinating in extreme conditions. However, the main avenue of establishment of deciduous species from an innoculum is likely to be from sucker and root sprouting rather than from seed.

Various deciduous species have been rated for their aggressiveness as invaders (Table 2). As data are limited, ratings are based on experience gained in reclamation programs throughout Alberta and through discussions with experts in woody plant establishment in Alberta. Some factors affecting the aggressiveness of a deciduous species are its ability to sucker, tolerance to heat and light and seed mobility. The time to seed bearing age is less important for deciduous species. Poplar seed is so highly mobile that seed will originate from the surrounding forest more often than from those planted, although species such as red-osier dogwood, bracted honeysuckle, and buckbrush have been known to produce seed on reclaimed areas just two years after planting (Monenco Limited 1983). Tolerance to heat and light is an important consideration in determining the aggressiveness of a species planted in open conditions. Combined with the silvicultural characteristics of each species the other most important factor affecting required initial stocking densities is the survival rate of the species.

Post-Mining Plant Communities - Suncor's Tailings Ponds

The location of the plant communities that become established will be governed primarily by drainage and topography. In the following discus-

TABLE 1
Seed and Seedbed Reproduction Variables

	White Spruce	Black Spruce	Paper Birch	Aspen	Balsam Poplar	Jack Pine	Alder	Tamarack	Bebbs Willow	Choke Cherry
Earliest Seed Production (year)	20	10	15	20	20	5-10	10	12-15	4	2
First abundant production (years)	45-60	25	40-70	50-70	20	40-50	25	40	25-75	n.d.
Seeds/tree	60 000 to 184 000[a]	3 500[b]	150 000[c]	1.5×10^6	1.5×10^6	11 000[f]	n.d.	300 000	n.d.	n.d.
Seed quality (percent of total crop)	45	47	20	95	95[e]	75	28	47	28	77
Dispersal Distance (m)	50-300	30	50	Long	Long[e]	Close to Parent	50	2x Height	Long	n.d.
Periodicity of seed crop (years)	3	4	2	4-5	1	4	1-4	3-6	1	1-2
Viable seed: seedlings ratio										
Mineral soil	12 to 24	3	20-400	1.4×10^6[h,i]	1.4×10^6[e,i]	6[j]	n.d.	n.d.	n.d.	5
Organic matter[g]	800 to 1000	100	400+	Impossible	Impossible	Impossible				
Seedling survival to 3 years (%)[k]	40	40	20[l]	20	5[m]	60[l]	5	4	10	30

Source: Zasada (1971). n.d. = no data

[a] Zasada (1971)

[b] From: 500 cones/tree (Zasada 1971); 11 000 cones/bushel; 3 oz. of seed/bushel of cones; 404 000 cleaned seed per pound (Fowells 1965)

[c] Assume a density of 1200 trees/ ha, 227 million seeds/ha (Zasada 1971) thus 189 367 seeds/tree, and thus conservatively 150 000

[d] Assumes 1000 catkins/tree (increase with age) (Fowells 1965) 1500 seeds/catkin for the closely related (*P. tremula*), and 100 seeds with cotton weighing 0.065 gms

[e] Thought to be same as aspen (Zasada 1971)

[f] Hellum (1983)

[g] Thickness of organic layer less than 8 cm except for black spruce (Zasada 1971)

[h] From: Shopik (1984) 700 gms of catkins/50 m^2, 100 seeds/0.065 gm (Fowells 1965), i.e. 1.0×10^6 seeds/50 m^2 with survival of 7.75 stems/50 m^2

[i] Seed viability very limited (Fowells 1965)

[j] On a burned seedbed (Ahlgren 1959)

[k] Conservative estimates from Shopik (1984 and 1985)

[l] Survival to end of 2 years (Shopik 1984)

[m] Low survival rate based on Monenco Limited (1983) and Shopik (1984 and 1985)

TABLE 2
Rating of Deciduous Trees and Shrubs on Silvical Characteristics Contributing to Successful Regeneration

Species	Suckering Ability	+	Tolerance to Heat and Light	+	Seedling Growth Rate	=	Aggressiveness
Northeast Poplar	5		5		5		15
Walker Poplar	5		5		5		15
Acute-leaf Willow	4		5		5		14
Balsam Poplar	5		5		4		14
Laurel-leaf Willow	4		5		5		14
Aspen	5		5		3		13
Glauca Willow	4		5		4		13
Rose	4		5		4		13
Sandbar Willow	4		5		4		13
Raspberry	4		4		3		11
Beaked Hazelnut	4		4		2		10
Bracted Honeysuckle	4		3		3		10
Choke Cherry	4		3		2		9
Pin Cherry	4		3		2		9
Red-osier Dogwood	3		3		3		9
Saskatoon	2		5		2		9
Green Alder	2		2		3		7
Paper Birch	2		3		2		7
Snowberry	3		1		2		6
Buffalo-berry	1		2		1		4

NOTE: Higher number means higher regeneration potential.

sion, recommendations are made for the establishment of plant communities, primarily for wildlife habitat, on the three main landforms, overburden, tailings sand slopes and tailings sand plateau areas associated with the post-mining environment on Suncor's lease area.

In poorly drained tailings sand and overburden areas a Poplar/Willow/-Alder/White Spruce association should be established. Portions of the tailings sand plateaus will have a very high water table. Such sites will be too moist for the establishment of jack pine. On moderately well and imperfectly drained overburden materials a White Spruce/Poplar/ Shrub community is recommended. The moisture conditions in these finer textured overburden materials is similar to that of the luvisolic soils on glacial till that support mixedwood stands in the natural environment. A White Spruce/Poplar/Shrub community is also suited to lower slope positions with northerly aspects on the tailings sand slopes. On off-mine sites these topographic positions are inhabited by mixedwood stands.

A Jack Pine/Poplar/Shrub community is recommended for the tailings sand slopes. The deciduous component of this community will, through suckering, aid in erosion control and stabilization of the slopes. However, competition from herbaceous species on these areas would have to be taken into consideration when determining innoculum planting densities. Survival rates on tailings sand slopes with competition from grass/legume species will be lower than where cereals are used because erosion is less of a concern.

On the well-drained tailings sand plateaus, our study indicated that a

Jack Pine/Poplar/Shrub community should be developed instead of the Jack Pine/ Bearberry/Lichen community previously recommended for these areas (Suncor Inc. Resources Group 1983) owing to the poor capability of this latter community to support wildlife.

Selection and Composition of Species for Wildlife Habitat

Selection of species for the creation of specific habitat types on reclaimed areas should be based upon: (1) the importance of the individual species in providing food or cover for wildlife; (2) the presence of the species in the natural community which is being re-established, and (3) the potential of the species to act as a pioneer or early successional species, noting that the composition of each plant community is extremely variable; both spatially and temporally.

Species composition in the natural communities is influenced predominantly by changes in microsite conditions. This same principle is expected to apply in the reclaimed landscape. Species more adapted to a specific microsite or those more competitive than their neighbor will succeed. In the design of an innoculum for the development of each community, the basic premise should be to provide a composition where each species has roughly equal opportunity to be represented in the final community. If each species has an equal opportunity to succeed, then those best adapted to each microsite or those with slight competitive advantages in each situation will dominate as the community develops.

The following sections specify plant species and composition for an innoculum for the development of each of the habitat types recommended.

Poplar/Willow/Alder/White Spruce. The moisture regime for areas where this community will be established will range from that found in the forest communities on alluvial soils to that found where this community has developed on gleyed soils. The most important species in these communities are balsam poplar, white spruce, alder, willow, dogwood and paper birch. As noted earlier, white spruce cannot be considered as an aggressive pioneer species. It is unable to reproduce vegetatively and does not produce seed for 20-30 years. White spruce is therefore not considered useful in providing an innoculum. In re-stocking white spruce on cutblocks harvested for timber, the normal practice is to plant in preferred locations seven years after the completion of logging. This practice allows for the introduction of spruce to occur in partially shaded sites as well as meeting the ten-year requirement of full stocking with three year old conifers. It is recommended that a similar strategy for the establishment of white spruce on reclaimed sites.

Because hybrid poplars and willow cultivars are some of the most aggressive species available for reclamation, they should be planted in this community. They will provide fast canopy closure and will ameliorate site conditions for the establishment of less tolerant understory species and white spruce.

The species composition of an innoculum which gives each of the recommended species roughly equal opportunity to be represented in the final stand can be calculated using the aggressiveness ratings developed earlier in the following way:

Species	Aggressiveness	Pro-rating	% Composition
Northwest poplar	15	1.00	7.4[a]
Walker poplar	15	1.00	7.4
Acute-leaf poplar	14	1.07	7.9
Balsam poplar	14	1.07	7.9
Laurel-leaf willow	14	1.07	7.9
Glauca willow	13	1.15	8.5
Sandbar willow	13	1.15	8.5
Dogwood	9	1.67	12.4
Alder	7	2.14	15.9
Paper birch	7	2.14	15.9
		13.46	100

[a] Pro-rated value expressed as a percentage of the total.

White Spruce/Poplar/Shrub. Mixedwood communities will be established on moderately well and imperfectly drained overburden materials. These communities are floristically the most diverse in this area. The most common species in these communities off the mine are white spruce, aspen, alder, rose, willow, lowbush and highbush cranberry, saskatoon, red osier dogwood, bracted honeysuckle and snowberry.

Lowbush and highbush cranberry, bracted honeysuckle and snowberry have not yet been established in trials on the mine. Data on the performance and survival of these species on overburden materials is not yet known. For this reason they have not been included in the recommended species composition for the innoculum of the mixedwood communities.

As with the Poplar/Willow/Alder/White Spruce community, hybrid poplars and willow cultivars should be included in the species composition. The rapid growth exhibited by these species will ameliorate the site allowing native species to invade. They will also provide a light deciduous overstory for the introduction of white spruce.

The species composition recommended for an innoculum for the establishment of White Spruce/Poplar/Shrub communities on moderately well and imperfectly drained overburden materials is as follows:

Species	Aggressiveness	Pro-rating	% Composition
Northwest poplar	15	1.00	7.1[a]
Walker poplar	15	1.00	7.1
Acute-leaf willow	14	1.07	7.6
Balsam poplar	14	1.07	7.6
Laurel-leaf willow	14	1.07	7.6
Aspen	13	1.15	8.1
Glauca willow	13	1.15	8.1
Rose	13	1.15	8.1
Dogwood	9	1.67	11.8
Saskatoon	9	1.67	11.8
Alder	7	2.14	15.1
		14.14	100

[a] Pro-rated value expressed as a percentage of the total.

Jack Pine/Poplar/Shrub. This community type is transitional between Jack Pine/Bearberry/Lichen communities on well drained areas and aspen dominated deciduous stands. The most important species in this community are jack pine, aspen, saskatoon, rose, buffaloberry and alder. This community is recommended for both the well drained plateau areas and the dike slopes. The establishment of this community on the plateaus instead of a Jack Pine/Bearberry/ Lichen community will increase the value of these areas for wildlife habitat. It is recognized however that some site amelioration may be required to establish some of the species on the very rapidly drained areas. It may be more effective to manage these rapidly drained areas for commercial forestry purposes rather than for wildlife habitat due to the superior drought tolerance of jack pine exhibited on rapidly drained sites. In either scenario, the species composition recommended here can act as an innoculum for either a Jack Pine/Bearberry/Lichen community or a Jack Pine/Poplar/Shrub community because stocking densities of 150 stems/ha of jack pine contain sufficient seed for the establishment of a fully stocked jack pine stand. It is acknowledged that only open grown jack pine on dry sites will release seed and regenerate.

The species composition recommended for an innoculum for the establishment of Jack Pine/Poplar/ Shrub communities on tailings sand areas is as follows:

Species	Aggressiveness	Pro-rating	% Composition
Jack pine[a]	N/A	N/A	N/A
Northwest poplar	15	1.00	8.4
Walker poplar	15	1.00	8.4
Aspen	13	1.15	9.7
Rose	13	1.15	9.7
Saskatoon	9	1.67	14.1
Alder	7	2.14	18.0
Buffalo-berry	4	3.75	31.6
		11.86	100

[a] Jack pine omitted here as it is not a species which can reproduce vegetatively or invade by suckering. Its planting density is determined only by survival rates. It is included in the final prescription in Table 3.

[b] Pro-rated value expressed as a percentage of the total.

Recommended Innoculum Planting Densities

Table 3 shows recommended stocking densities of the most important species in the three recommended plant communities. Stocking rates for an innoculum of 300 and 600 surviving stems/ha are given for both tailings sand and overburden. Both of these surviving stock rates are considered sufficient for the development of each community. The difference between the two rates will be the amount of time necessary for the development of a complete canopy cover. There are no data to indicate the differences in the time frames required.

Survival rates used are those from Shopik (1984 and 1985) for tailings sand and overburden in either a sparse or established cover. Survival data are limited and do not allow for the provision of stocking rates for both grass/legume and cereal cover types. If survival rates are improved using new techniques (e.g. barley for cover crop, and larger, more vigorous stock), it is possible that initial stocking rates to obtain the innoculum of 300 and 600 surviving stems/ha can be reduced accordingly.

Jack pine densities in the Jack Pine/Poplar/Shrub community are specified to provide 150 surviving stems/ha for both tailings sand and overburden. This density is considered sufficient for the natural perpetuation of either a fully stocked pine stand or a mixed pine/deciduous stand.

White spruce stocking densities are not specified for the two communities where it appears. This species is not recommended for use as an innoculum but should be planted in densities commensurate with the final densities required following the establishment of a light overstory.

Acknowledgements

The ideas expressed here were first formulated during a study in which Suncor Inc. Resources Group required us to determine what innoculum stocking densities should be used on their reclaimed land with the objective being to reclaim the land in the same time frame as that following a disturbance such as fire. We thank Suncor Inc. Resources Group, especially Tim Shopik, for allowing us to publish these ideas.

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TABLE 3

Recommended Innoculum Planting Densities for the Establishment of Three Plant Communities for Wildlife on Tailings Sand and Overburden

Community Type	Species	Percent of Total Stocking Density	Average Percent Survival		Innoculum Planting Density[a]			
			Tailings Sand	Overburden	Tailing Sands		Overburden	
					300	600	300	600
Poplar/Willow/Alder/ White Spruce	Balsam poplar	8	-[b]	22	-	-	109	218
	Walker poplar	7	48	52	44	88	40	80
	Northwest poplar	7	48	52	44	88	40	80
	Acute-leaf willow	8	50	50	48	96	48	96
	Laurel-leaf willow	8	50	50	48	96	48	96
	Sandbar willow	9	-[e]	50	-	-	54	108
	Glauca willow	9	-[e]	50	-	-	54	108
	Alder	16	21	30[c]	229	458	160	320
	Dogwood	12	7	44	514	1028	82	164
	Paper birch	16	37	17	130	260	282	564
	Total	100			1057	2114	917	1834
White Spruce/Poplar/Shrub	Aspen	8	48	62	50	100	39	78
	Balsam poplar	8	-[b]	22	-	-	109	218
	Walker poplar	7	48	52	44	88	40	80
	Northwest poplar	7	48	52	44	88	40	80
	Glauca willow	8	-[e]	50	-	-	48	96
	Laurel-leaf willow	8	50	50	48	96	48	96
	Acute-leaf willow	8	50	50	48	96	48	96
	Alder	15	21	30	214	428	150	300
	Rose	8	64	70	38	76	34	68
	Saskatoon	12	23	56	156	312	64	128
	Dogwood	12	7	44	514	1028	82	164
	Total	101			1156	2312	702	1404
Jack Pine/Poplar/Shrub	Jack pine	N/A[d]	33	54	450	450	278	278
	Aspen	10	12	48	250	500	63	126
	Northwest poplar	8	48	52	50	100	46	92
	Walker poplar	8	48	52	50	100	46	92
	Saskatoon	14	17	23	247	494	183	366
	Alder	18	21	30	257	514	180	360
	Rose	10	64	70	47	94	43	86
	Buffalo-berry	32	42	55	229	458	175	350
	Total	100			1580	3160	1014	2028

[a] Planting Densities for final innoculums of 300 and 600 plants/ha given.
[b] Balsam Poplar excluded due to very low survival on tailings sand.
[c] Assumed that Alder survival 10% higher than on tailings sand.
[d] Not applicable - in the absence of fire jack pine does not regenerate.
[e] Glauca and Sandbar Willow omitted in tailings sand due to very low survival.

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REVEGETATION AND ECOLOGICAL MONITORING OF AN OPEN CAST ROCK PHOSPHATE MINE[1]

BY

[2]P. Soni, H.B. Vasistha, O. Kumar, V. Bhatt and M. Negi

Abstract. The paper presents results of a revegetation programme to stabilize on excavated rock phosphate mine area. The programme emphasized on using ecologically, economically and socially viable plant species which resulted in "Green revolution" of the degraded mined area within a short span of six years.

Details of reclamation methods adopted, results of ecological monitoring of floral and faunal density and diversity in revegetated areas have been presented.

Additional Key Words : Revegetation, diversity, ecological monitoring.

Introduction

Mining is one of the important industries of India, next only to agriculture in importance and is hence linked directly with country's rapid industrial and energy development.

Large areas are subjected to mining of minerals like coal, iron, manganese, copper, gold, rock, phosphate, limestone etc. in about 5000 mining leases spread over about .7 million hactares area of the country (Mathur 1978).

It is also a fact that most of the mining leases occur in heavily wooded areas and hence damage to forests is inevitable. Once the area is subjected to mining, the ecological impacts are much more diverse depending on the type of mining, ore excavated, ore: overburden ratio, geology and terrain of the area where mining is being done.

Due to lack of stringent environmental regulations in our country, most of the mined areas are in an environmentally disturbed state. Erosion of abandoned, underclaimed mine sites has resulted in the degadation of aquatic life in receiving streams (Brenner et.al.1978; Kimmel 1983; Muncy 1986). In India reclamation of mined areas is of recent origin and hence there are only a few mining companies which have undertaken reclamation of their mined areas in a scientific manner.

Reclamation of excavated mine areas basically involves two steps - i) site preparation by grading, construction of check dams, gabions or other mechanical structures depending on site condition, geology etc. ii) revegetation of the site by planting, seed sowing of suitable species of trees, shrubs and grasses etc.

In the present study reclamation of an open cast rock phosphate mined area was under taken with the collaboration of the mining company, M/s Pyrites Phosphate and Chemicals Ltd., Dehradun. This reclamation project was under taken with following major objectives :-

1 Since the area has slopes of 30-40°,erosion control was the foremost requirement.

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[1] Paper presented at the Conference Reclamation, A Global Perspective,held in Calgary, Alberta, Canada August 27-31, 1989.

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2. Water quality of a stream flowing down below was to be controlled.
3. Restoration of site ecology.
4. Socioeconomic return from the area on a sustainable basis.

Experimental Site

The mining site about 10 ha. in size, is located about 18 km. North east of Dehradun town. The elevation of the site ranges between 750 and 1050 mean sea lavel. The area is represented by tropical monsoon type climate, with an average annual rainfall of 2500 mm.

On the basis of geological formation, three sub sites of the mined area were selected, as well as one natural forest plot, which is not affected by mining, for comparison of results -

1. Overburden dumps containing mainly shale (60-70%), limestone and chert (20%) and about 10% soil.
2. Exposed black pyritic shale
3. Weathered limestone
4. Natural forest

Reclamation Methods

To control erosion of soil, a series of gabion check dams and stone walls were constructed along the slope length so that loose overburden may be partially retained. Along the perennial river flowing below the mining area, a 200 m long stone wall was erected to check the inflow of debris into the stream water.

Once the mechanical measures were complete, biological reclamation of the area was begun. Since the aim of this particular reclamation project was to be ecologically based, the biological reclamation process was carried out in the following sequence:

1. Ecologicaly survey of the adjoining undisturbed forests to select ecologically adapted species of the region which are useful for the localinhabitants wildlife and humans both and have high colonizing and erosion control capability.

2. Based on the above survey, seeds and cuttings of species from adjoining areas were collected.

3. The seeds of the following species were broadcast seeded over the whole area :

Buddleja asiatica, *Eriophorum comosum*, *Crotolaria sericea*, *Mimosa himalayana*, *Rumex hastatus*, *Trema politoria* and *Wendlandia exserta*.

Cuttings of the following species were collected and planted as indicated against each :-

Ipomoea carnea	in contour trenches
Jatropha curcas	for gully
Moringa pterygosperma	plugging
Salix tetrasperma	Along water courses
Saccharum spontaneum	Root tiller on lime stone areas
Vitex negundo	Shoot cutting

Besides local grasses, shrubs and trees, some other species were also planted in contour tremches i.e. Arundo donax and Pennisetum purpureum,

With the introduction of the fast growing species listed above, the area was partially stabilized in one year. Subsequnet planting of following tree seedlings on a large scale was undertaken;

Acacia catecheu, *Moringa pteruygosperma*, *Dalbergia sissoo*, *Melia azadiracht*, *Caraya arborea*, *Leuceana leucucephala*, Tropical Pines:

Pinus caribaea bahamensis var, Queensland, Australia, *P.elliottii* Queensland Australia, *P. Caribaea* var,hondurensis Poptun-paten Guatamala *P.Caribaea* a var. hondurensis lostimones and *P.Caribaea* var hodurensis Brazil.

List of ornamental species planted at the mining site:

Bauhimia variegata
Bauhinis retcusa
Callistemon viminalis
Cassia glauca
Cassia fistuala
Cassia javanica
Cinnamomum camphora
Jacaranda acutifolia
Legerstroemia indica
Delcnix regia
Francia sp.
Gardenia florida

After a period of 5 years of reclaimation in 1987, when the site turned completely green and was erosion free, the following ecological monitoring of the site was initiated

i) Plant and soil faunal population changes: Quadrats of 10 sqm.,5 sqm.and 1 sqm. were

TABLE -1 Name of species and mode of propagation

Herbs, shrubs & grasses	Seed	Cutting	Root stock	Bulbils	Seed ling	Total No.of plant	%sur vival
Buddleia asiatica	✓	-	-	-	-		60-70
Mimosa himalayana	✓	-	-	-	-		60-70
Pennisetum purpureum (Hybrid napier)	-	-	✓	-	-	2400	100
Rumex hastatus	✓	-	-	-	-		90
Saccharum spontaneum		-	✓	-	-	500	100
Vitex negundo		-	-	-	-	1000	30
Tree species		-	-	-	-		
Acacia catechu		-	-	-	✓	3000	98
Dalbergia sissoo		-	-	-	✓	4800	98
Leuceana leucocaphala		-	-	-	✓	500	98
Salix tetrasperma		-	-	-	✓	4000	80

used to ascertain density and frequency of trees, shrubs and grasses respectively in all the sites.
A core of 10 cm was taken and faunal population was estimated by dry sieving, by use of hand sorting and a Berlese funnel.

ii) Litter production and nutrient composition:
Litter production in all the areas was collected from 1 sqm. plots and analyzed for nitrorogen,phosphorus, calcuim, pottassium magnesium (Wilde et.al.1985).
Litter production,and nutrient composition
A core of 10 cm was taken and the faunal population was estimated by dry sieving, and by use of hand sorting and a Berlese funnel.

Results and Discussion

Results of the study are presented in two parts, firstly the results of bioreclamation and then ecological monitoring of reclamation sites.

Percentage survival of plants on mined out areas and overburden dumps was found to be very encouraging especially for local species (Table-I) of trees like Dalbergia sissoo, Acacia catechu. However Pinus sp. showed very poor survival rate of only 10-15%.

Similarly, local shrub species showed very encouraging results. Ipomoea carnea and Vitex negundo raised from cuttings gave almost 95% survival. Besides these Pennisetum purpureum, Arundo donax and Sacoharum spontaneum showed 90-95% survival.

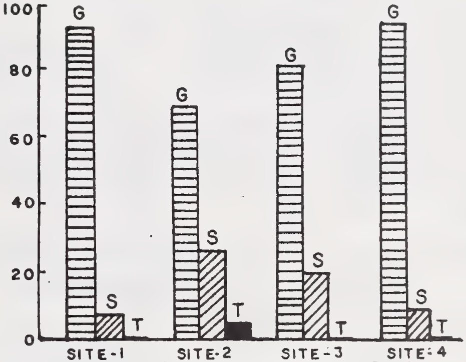

Fig.1 % contribution of different plant groups

Resutls of floristic composition have shown that diversity of plants has increased significantly from the initial zero level. In reclaimed areas, besides the species of trees, shrubs and grasses planted/raised for reclaiming the area, quite a good number of species in all categories have invaded.(Table 2,fig. 1) Vegetation survery of all the mine sites and that of adjoining natural forest shows that the reclamation process has favoured the increasing diversity levels(Table 3).

The floristic structure of the mined area shows that the total number of plant species on the reclaimed site is nearly equal to, or more than the undisturbed forest. Herbs and grasses are the highest contributors to total density followed by shrubs and trees. The data thus clearly indicate the initiation of natural succession in a short span of 4-5 years after

TABLE – 2 Floristic composition of all sites after five years.

Group of plants(No. of spicies)		Site I	Site II	Site III	Site IV
herbs and grasses.	Planted	* 23,300	** 7,128	** 13,300	–
	Natural	5,34,500	43,464	89,800	1,86,400
Shrubs	Planted	29,596	1,600	*** 12,792	
	Natural	8,256	17,316	11,564	7,864
Trees	Planted	2,833	3,199	499	–
	Natural	33	–	–	1,561
Total		5,98,518	72,707	1,27,955	1,95,825

* Represents shrub seedlings raised on the site

** Includes planted shrub and tree seedlings besides planted grass species

*** Includes planted/raised tree seedlings

reclamation. Further, the development of vegetation on the sites has resulted in litter production through leaf fall (Table 4). It is well known that litter production and its subsequent decomposition is of great significance in improving the site conditions through nutrient enrichment and for establishment and growth of vegetation on surface mine sites (Brenner, Werner and Pike 1984).

TABLE 3– Number of species of each plant group and their percentage contribution to total plant density hectare.

	Site I	Site II	Site III	Site IV
Herbs & grasses	16 (93.19%)	9 (69.58%)	9 (80.57%)	9 (95.18%)
Shrubs	11 (6.32%	7 (26.01%)	14 (19.03%)	11 (4.01%)
Trees	4 (0.47%)	4 (4.39%)	4 (0.39%)	8 (0.80%)
Total No. of species	31	20	27	29

Table 4 and fig.2 give the amount of litter (in kg/ha) produced in different sites and also nutrient content: Nitrogen, phosphorus, potassium, calcium and magnesium (kg/ha) in the respective sites. Litter production per hectare is found to be maximum in site III followed by site 1. This is much more than the amount of litter collected from the natural forest which is only 433.0 kg/ha. These results further support the observations that reclamation through ecologically adapted species is valuable in ameliorating the mined sites and providing food and cover for faunal species. As the floral density increases, the same trend is being followed by faunal density.

TABLE – 4 Production of liter (kg./ha) and nutrient content(kg/he) in mined and natural forestr areas

	Site I	Site II	Site III	Site IV
Oven dry litter	789.00	513.00	1025.00	433.00
Nitrogen	1.32	1.16	0.84	1.09
Phosphorus	0.33	0.20	0.30	0.27
Potassium	0.26	0.18	0.27	0.26
Calcium	2.33	1.41	0.93	1.00
Megneshium	0.50	0.77	0.50	0.30

This preliminary survey has shown that site I has the maximum faunal communities,where density of herbs and grasses was maximum and contribution of shrubs and trees was comparatively low. It may be presumed that the acquired stability from erosion and sliding results in higher biomass production, subsequent decomposition of litter and this helps in enrichment of the mine spoil fauna. The final

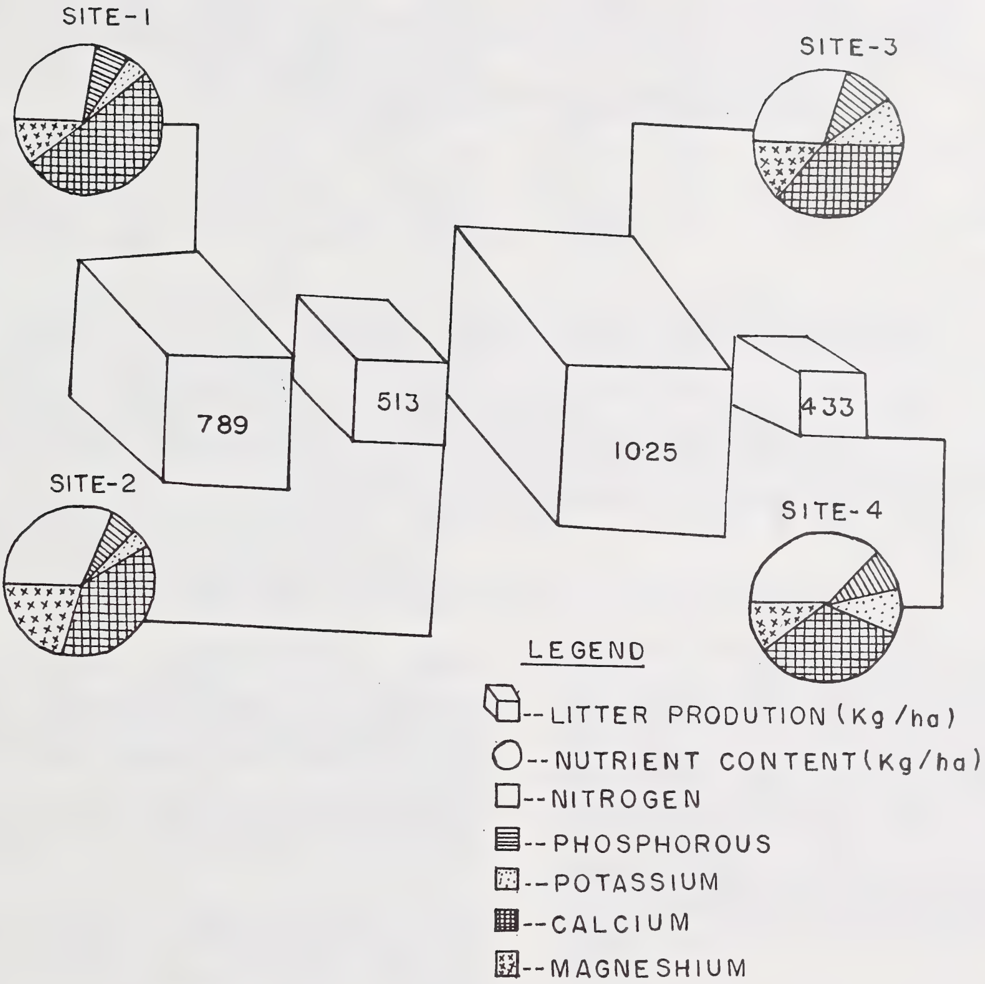

FIG.2 LITTER PRODUCTION AND NUTRIENT CONTENT IN Kg/ha

influence of vegetation (Neumann 1977) supports that the area planted with trees producing high amounts of readily decomposable litter support more decomposer organisms (Cruestacea). The results of the survery indicate that site 1(Table 5 has the maximum soil fauna. The major soil inhabiting group observed is the same as in the natural forest (fig.3) but site 1 has the maximum density/cum. in comparison to natural forest. It was also noted that Myriopoda and Mollusca are totally absent in site 2 and 3 but these two groups are present in site 1 and site 4 (adjacent natural forest). The most dense and diverse plant cover in site 1 shows the composition of the fauna also increases propostationately and through it the quality of the humus may be improved for plant growth (Table 3). These findings are also supported by Murphy (1953 and 1966)). In the course of the further development of the soil Formicomus castigator (Coleoptera), Cremastogaster wroughtom (formicidae) forms large clumps in which a rich soil fauna can develop. Animals appearing here include Rhysida nuda (Scolopendromorpha), Isopoda (families not yet identified), Arneae (Cyrotophora Gnaphosa, Meta sp.) because they are the first coloniziers which bring about mixing of humus, clay and enrich the fertility

TABLE-5 Density of different faunal groups in different sites.

Soil faunal group	Density/cum Site I	Site II	Site III	Site
Arachnida	1499	833	1833	833
Crusracea	500	500	166	1500
Myriopoda	333	-	-	333
Insects	13999	6833	6166	3166
Mollusca	1333	-	-	3833
Total	17666	8166	8166	9666

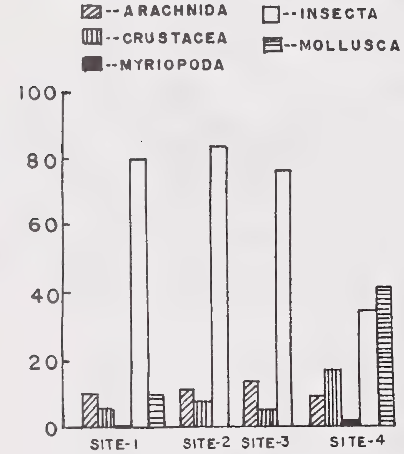

Fig.3 % contribution of soil faunal groups

of soil.

Ecological findings of the reclaimed plots and their comparison with the adjoining natural-forest plot lead to the conclusion that reclamation of mined sites with local species of herbs, shrubs, grasses and trees builds up the ecosystem in a favourable manner such that succession of flora and fauna starts. This further results in stabilizing the area from sliding and erosion as well as ameliorating the soil conditions.

Further use of local colonizing species restores the site in an inexpensive manner ($.16/cum of overburden reclaimed in the present study) and fulfill the requirements of local inhabitants in a sustained manner.

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SUCCESSIONAL RECLAMATION IN WESTERN CANADA: NEW LIGHT ON AN OLD SUBJECT [1]

by

David F. Polster [2]

Abstract Successional reclamation is defined as the enhancement of natural successional processes for rehabilitation of drastically disturbed sites. Formulation of grass and legume seed mixes which enhance natural successional processes is described. The use of key pioneering woody plant species and the dynamics of vegetation succession are discussed in the context of reclamation of western Canadian sites. The benefits of using the successional reclamation approach in terms of improved species performance, decreased cost, and enhancement of ecological stability are discussed. Development of bioengineering techniques for use on difficult sites is discussed with reference to techniques, costs and benefits. Key factors in the planning of a successional reclamation program are detailed. Examples are drawn from reclamation programs conducted at mining and other industrial sites.

Additional Key Words: natural successional processes, bioengineering, difficult sites.

Introduction

Reclamation of drastically disturbed lands has developed over the past several decades to the point where reclamation considerations are now an integral part of the development process (Thirgood 1986). Details of soil conservation measures as well as revegetation prescriptions are now a standard part of most major mine or industrial developments (Ziemkiewicz et al. 1980). Techniques for the revegetation of disturbed sites have been developed using modified agricultural and forestry methodology (Errington 1988). In general, reclamation practitioners have succeeded in the "re-greening" of disturbed sites.

Reclamation designs have been developed to return the land to a productivity which is as great or greater than that which was supported prior to the disturbance. Recreation of wildlife habitats, restoration of watershed values, development of agricultural lands and the development of productive forests are but a few of the many land uses which reclamation programs have been designed to meet. In cases where the disturbed land is to be continually maintained, such as under agricultural production, most reclamation programs have worked well. However, where the disturbed lands are to be returned to some "natural" state, most of the reclamation programs which have been developed have fallen short of the desired results. This paper describes a reclamation format which addresses these shortcomings.

Successional reclamation is the term applied to the re-establishment of the natural successional processes on disturbed sites. The primary thrust of the successional reclamation process is the development of soils and vegetation patterns which will allow the site to return to the natural successional processes which would, over time, revegetate the site. It is clear that most sites which are being reclaimed were, prior to the creation of the disturbance, vegetated. By directing reclamation efforts into the re-establishment of the natural successional processes, the forces which act to vegetate the surface of the earth can be used to develop a vegetation cover on disturbed sites.

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[1] Paper presented at the Canadian Land Reclamation Association and American Society for Surface Mining and Reclamation conference, Calgary, Alberta, August 27-31, 1989.

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There are a number of benefits to utilizing a successional approach in the development of reclamation programs. The primary benefit is that such an approach will, in the long term, be more effective. Costs will be less, and the cover which eventually establishes will be self-sustaining. The following sections of this paper explore the use of successional approaches in the development of effective reclamation programs.

Successional Processes

Vegetation succession may be defined as the changes in plant species composition which result from the ability of different species to utilize different niches (Oosting 1956). The presence of the plants changes the environment in which they are living, creating new niches for different species, and so the process continues, with differing assemblages of plants developing on any given site until the climatic climax vegetation develops. As shifts in the climate occur, over geologic time periods, different assemblages of plants develop. The propensity of plants to colonize areas which have been devoid of plant life is the key to the succession process.

Primary successional processes develop on sites where there has never been a cover of plants. This may be on a recent lava flow, or on recently deposited mine wastes. In North America, lichens are generally the initial colonizers of bare rock. The ability of the lichens to synthesize nitrogen from the air, and the development of organic acids which break down the rock into soils, enables other plants to establish. Eventually, over centuries, the area which was once bare rock is vegetated.

Secondary successional processes occur where vegetation has been removed from the site but where the effects of the vegetation which was on the site are still felt. Fire, land clearing and other such activities initiate the process of secondary succession. In cases where soils .have been salvaged for later use in the reclamation of a site, the successional processes which will occur on the site will be secondary successional processes.

Successional reclamation processes are founded on a clear understanding of the natural successional processes which would occur on the site being reclaimed given sufficient time. In effect, it is the enhancement of these natural processes which is the basis of the successful successional reclamation program. The following sections of this paper describe the development of a typical successional reclamation program.

Pioneering Species

Establishment of the initial cover of vegetation on the reclamation site is often the most challenging task facing the reclamation practitioner. The factors precluding vegetation must be evaluated and species which will ameliorate these adverse factors sought. Conditions such as low nutrient status, poor moisture and nutrient holding capabilities, and adverse physical conditions of the substrate are common on reclamation sites. Adverse chemical characteristics such as presented by sodic spoils or acid generating wastes may also present barriers to plant growth and development. Selection of species which have evolved to develop in situations where these adverse conditions naturally occur will initiate the process of successional reclamation.

In general, pioneering species should be selected on the basis of their ability to perform some function which will ameliorate the adverse conditions of the site and allow future species to establish. The following paragraphs outline some of the commonly occurring barriers to plant growth and the species characteristics which can be utilized to overcome these barriers.

Low Nutrient Status

Nitrogen is the nutrient which is most commonly limiting on reclamation sites. Species which will fix atmospheric nitrogen and make it available for other plants must be considered in the selection of pioneering species. Legumes, such as clover and alfalfa are excellent in this capacity. Other species such as alder, buffaloberry, mountain avens and native legumes can also aid in the amelioration of low nutrient status sites. Other nutrients may be added with fertilizers.

Poor Moisture and Nutrient Retention

A general lack of soil organic matter can result in an inability of the site to retain nutrients and moisture, limiting plant growth. Species which will incorporate significant amounts of organic matter will aid in ameliorating these deficiencies. Fine textured mineral soils such as clays can also be used to improve the nutrient and moisture retention status of the site. Grasses can contribute organic matter both through root decomposition and through above ground biomass.

Adverse Chemical Characteristics

Selection of species which have developed a tolerance to the particular conditions being experienced can initiate the process of natural succession on these sites. For instance, Distichlis stricta (Torr.) Rydb. develops naturally on saline areas on the Prairies. This species contributes to the amelioration of the saline conditions through the incorporation of organic matter and improved drainage. In some cases, it may be necessary to physically ameliorate the adverse condition prior to the establishment of vegetation. Weathering, which will in the long term reduce adverse soil conditions, can be enhanced through the incorporation of additives.

Adverse Physical Conditions

Adverse physical conditions such as steep or unstable slopes can be treated with species which would naturally pioneer on such sites. Areas of groundwater induced instability are colonized naturally by willows, poplars and other such species. Similarly, areas which are oversteepened and are continually moving, will be colonized by species which have adapted growth forms which can accommodate such conditions. Willows will resprout from buried stems, and can be used to stabilize oversteepened slopes. Once the site is physically stabilized, the establishment of additional species is possible and the natural successional process can develop.

Fostering Successional Processes

Successional reclamation programs are designed to enhance the further development of vegetation on the site. There are two features of the site which will allow this to occur; the development of spaces which the invading species can occupy, and the modification of the initial site conditions to allow other, different species to develop. These factors are discussed in the following paragraphs.

Space for Others

Provision of space into which invading species can establish will enhance the potential for further succession. Every golf course keeper knows that the best way to prevent the invasion of weeds onto the fairways is to maintain a dense stand of the desired grasses through fertilization and watering. Once there are spaces between the grass plants, other species, which in the case of the golf course, are undesirable, soon invade. The same holds true for the reclamation site, except in this case, the invasion by additional plant species is often desired. The stand of pioneering vegetation must be open enough to allow for the invasion of the secondary species.

Grasses and legumes are often used by the reclamation practitioner as the pioneering vegetation. These are seeded onto the site to reduce erosion, enhance fertility and provide cover for other more permanent species. The development of grass and legume seed mixes which are designed to allow spaces to develop between the plants will foster the successional process. The use of bunch forming species, and limiting the use of sod forming species will aid in this process. Similarly, species which are relatively short lived can also be used to provide space for invading species. Limitations must be placed on the use of fertilizers which enhance the growth of the grasses and legumes at the expense of the invading species.

Seed mixes must be balanced according to seed weights to achieve the desired end results. Seed is sold by weight, so a mix composed of 50% bluegrass and 50% brome would have equal weights of both species. However, by species composition the mix would result in a stand which would be 94.5% bluegrass. This might be fine for a lawn, but in a successional reclamation program, it would not leave room for invasion by other species. Dense stands of single species, or closely related species, which do not allow room for invaders result in a stagnation of the successional process which will persist until some change in the system occurs. In the example given above, the bluegrass stand would persist until there was some change such as a reduction in the nutrient status which allowed other species to invade.

Modifying Site Conditions

Pioneering species modify site conditions to permit the establishment of the invading species. In most cases, there are a variety of conditions which must be modified prior to the successful establishment of the secondary species. For instance, mountain avens (Dryas drummondii Richards) is a pioneer on gravel bars in the Rocky Mountains (Fyles 1976). It forms dense mats of vegetation which initially precludes the invasion of other species. However, as the plant expands, the older portions die, leaving space for other species such as spruce and cottonwood to invade. The initially harsh conditions of the gravel bars, notably lack of nutrients and lack of soil organic matter, are ameliorated by the mountain avens.

Species such as alder, which is commonly used as a secondary species in successional reclamation programs, may modify site conditions in a variety of ways and allow the enhanced growth and development of conifers. Alder fixes nitrogen, and can provide up to 62 kg/ha/yr of fixed nitrogen (Haeussler and Coates 1986) for other plants to use. Alder can also ameliorate micro-climatic conditions for young conifers. In the early spring, when soil temperature are low and growth is limited by the low soil temperatures, the alder allows a maximum amount of sun light to reach the ground. However, during the heat of the summer, the alder shades the young conifers, with the canopy providing a trap to prevent moisture loss by the young plants. Care must be taken however to ensure that the canopy of alder does not reduce light intensities below the light compensation point for the young trees (R. Stathers 1989, pers. comm.). For the British Columbia Interior, alder stocking rates of 3,000 stems/ha appear to be ideal in terms of aiding in conifer growth.

Successional approaches to the reclamation of disturbed sites can lead to enhanced ecosystem stability. The development of reclamation systems which are open to invasion by new species and the enhancement of natural ecosystem repair mechanisms leads the reclaimed environment to become more heterogeneous. This diversity in the reclaimed system results in a greater opportunity to accommodate perturbations in the system. In addition, the potential for significant perturbations is reduced in the reclaimed lands because of the natural feedback mechanisms which tend to limit such problems. For instance, large increases in small rodent populations are well known in traditional reclamation environments. Mice and voles thrive in the protection of a dense cover of grasses and legumes. The grasses and legumes provide a cover for these animals from their natural predators. However, in a successional reclamation environment, population explosions are limited by the open nature of the initial cover. Predators can control these populations, leading to a healthy predator/prey relationship.

Productivity of sites reclaimed using successional approaches develops to the optimum for the site without the need for continual maintenance or external inputs. Vegetation develops naturally to optimize the use of all available niches. Maximum productivity in natural systems is achieved at a state immediately prior to the establishment of the climax vegetation (Whittaker 1973). Development of reclaimed systems which mimic the natural successional processes will lead to maximum utilization of the available niches. It should be noted that this considers only systems which are not supplied with external inputs such as fertilizer. It also relates to natural vegetation processes, not artificial systems such as an agricultural development.

An understanding of the successional processes which drive vegetation establishment and development can lead to a manipulation of these systems to achieve some desired end result. The artificial enhancement of early successional stages can be used to maintain these systems. Revegetation design for some sites may seek to preclude the growth of woody species. By limiting the space into which woody species would invade through the use of sod forming species and additional fertilizers, further succession can be limited. It should be noted that this process, however, is only temporary, and without the additional input of fertilizers and other maintenance, the natural forces of succession will eventually result in the establishment of woody species.

Difficult Sites

Successional reclamation methods provide an ideal approach to the reclamation of difficult sites. Bioengineering techniques, where living plant materials are used to perform some engineering function, fit neatly into the successional reclamation process (Schiechtl 1980).

Wattle fences, where living willow, poplar and red-osier dogwood cuttings are used to construct short retaining walls have been used to initiate successional processes at a number of sites in western

Canada. The fences are constructed at frequent intervals up steep slopes, breaking the slope into a series of short, shallow slopes which can then support vegetation. The materials used to construct the fences sprout and grow, resulting in an initial cover of the pioneering species which were used. Slopes of 50 to 60 degrees are treated with wattle fences.

Live pole drains are used to drain excess moisture from sites where the moisture is causing soil stability problems. Live pole drains are constructed of bundles of living cuttings placed in shallow trenches in the problem area. The drains initially act by draining moisture through the voids created by the bundle of cuttings. As the cuttings grow, excess moisture is removed by transpiration of the plants. The root systems also tend to hold the soils in place. Live pole drains are built using species which would naturally invade on wet seepage sites, again initiating the process of succession.

Living baffles are used to control erosion in drainage channels and erosion gullies. The baffles are built of living cuttings laid across the channel to slow the flow of water. As the baffles grow, the channel becomes lined with the vegetation which would naturally develop on such a site.

Other bioengineering techniques, such as brush layering, hedge brush layering, the use of living cuttings to hold sod in place on steep slopes and soil binding seeding make use of the concepts of successional reclamation by utilizing plant materials to solve the problems which were precluding plant growth initially. Once these initial problems are solved, further vegetation can establish on the site.

Conclusions

Successional reclamation is the term applied to the re-establishment of natural successional processes on reclamation sites. By utilizing the natural forces which act to revegetate sites, reclamation processes can be enhanced. These natural processes can be harnessed to revegetate sites which for a variety of reasons would not easily support vegetation. Significant savings in terms of cost and effort can be realized by using successional approaches to the reclamation of disturbed sites. Sites which would otherwise require significant civil engineering works can be stabilized and revegetated using successional approaches. An understanding of the natural processes which act to develop vegetation on a site and the incorporation of methods which enhance these processes will result in a more efficient utilization of resources and better results in the long term.

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FIRST-YEAR EVALUATION OF EXCELSIOR PADS ON LOBLOLLY PINE[1]

by

Walter H. Davidson[2]

Abstract. In the spring of 1988 I conducted a study to test the effects of excelsior pads on loblolly pine survival and growth. Two types of pads were used: American Excelsior Company TREGRO type 100 and 200.[3] Bare-root, 1-0 loblolly pine seedlings were mattock planted on April 14 and the pads installed on April 15. The study design was random pairs of treatment (with pad) and control (no pad) seedlings. An evaluation on May 5 showed inconsistent survival that was attributed to planting technique. Three people planted seedlings: two had survival rates of 95 percent while the survival rate for the third planter was 77 percent. Evaluation at the end of the growing season showed that the pads had no apparent influence on survival. Overall survival was 72 percent with pads and 71 percent without pads. The initial mortality was distributed evenly among treatments, so subsequent measurements were not biased. Nevertheless, seedlings with the type 200 pads were significantly taller than controls or type 100 seedlings. These results show: (1) there is no substitute for good planting technique to ensure seedling survival, and (2) type 200 TREGRO pads have a beneficial effect on seedling growth even under the severe drought conditions of 1988.

Additional Key Words: surface mining, reclamation, West Virginia.

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[3] The use of trade, firm, or corporation names in this publication is for the information and convenience of the reader. Such use does not imply official endorsement by the U.S. Department of Agriculture or the Forest Service of any product or service to the exclusion of others that may be suitable.

Introduction

Tree planting for surface mine reclamation has been on the decline since the passage of the Surface Mining Control and Reclamation Act (PL 95-87). The requirement for a herbaceous cover has introduced a competition factor that has all but eliminated tree planting. Many techniques have been attempted to alleviate this problem but none have been totally successful. Mulches have been used both on minesoils and other sites to enhance tree establishment and growth. In studying the use of black polyethylene versus mechanical cultivation on the establishment and growth of hybrid poplar, Bowersox and Ward (1970) reported that polyethylene gave equal results in a prolonged drought and improved both survival and growth in periods of normal rainfall or limited drought. Bark or wood-chip mulches were recommended by Vogel (1981) to aid tree establishment on minesoils. Slick and Curtis (1985) found that mulches also can reduce frost heaving of tree and shrub seedlings. In most reclamation plantings, however, the only mulches used are those that can be applied with a hydroseeder and application rates are too low to aid trees or shrubs.

In the spring of 1988, the American Excelsior Company provided us with TREGRO pads for test purposes. After examining them, we decided to purchase additional pads for use in a field experiment. The major attributes of the pads, as indicated in the promotional materials, are that the pads retard weed growth, aid in moisture retention around the trunk area, and minimize trunk damage by mowing equipment. Even though the pads are relatively expensive for major reforestation projects, it was felt that a knowledge of their capabilities would be helpful in defining problems associated with tree establishment on reclaimed surface mines and other disturbed areas.

Methods and Materials

A recently reclaimed surface mine in Raleigh County, West Virginia, was selected as the site for the test. Two types of pads were used: Type 100 and Type 200. The entire surface of Type 100 pads is enclosed in a white polypropylene netting. The netting has six (6 by 6) strands per square inch. The entire surface of Type 200 pads is covered with black 3/4x5/8-inch polypropylene netting. The downside surface has a geotextile fabric enveloped within the netting. Both types are available in two sizes, 3 by 3 and 4 by 4 feet. We used the 3 foot size. The pads are held in place with wire staples having 6 inch legs and 1 inch width. Nine staples were used per pad for anchorage. The T100 pads cost \$1.65 each and the T200 pads cost \$2.25. When cost of shipping and staples was added, individual costs were \$2.15 and \$2.75, respectively.

The planting medium consisted of a mixture of topsoil and subsoil. It was somewhat rocky and had a pH of 4.5 to 5.0. At the time of planting, the soil was moist.

One-year-old loblolly pine seedlings, averaging 15 to 20 cm in height, were mattock planted on the site on April 14, 1988. The portion of the planting with loblolly pine consisted of four rows with a total of 402 seedlings. The area had been hydroseeded to a herbaceous mixture about 2 weeks before planting. Emergence of grasses and clover had just begun.

Pads were installed around the seedlings on April 15. Trees in each row were paired. Then a pad or no pad treatment was randomly assigned to the first member of each pair. There were 201 pairs: 102 with T200 pads and 99 with T100 pads. One person, working alone, installed the pads in 7 hours.

Results

An inspection of the planting on May 5 showed that 45 seedlings (11 percent) had died. Much of the initial mortality appeared to be planting error. There were 34 dead seedlings in the row planted by one person and 7 and 4 dead in rows planted by two others. This initial mortality is not related to the presence or absence of TRE-GRO pads, but does re-emphasize the need for care in planting seedlings.

Evaluation of the planting in mid-September showed that mortality had increased to 28 percent. The ratio of dead trees by planter remained about the same as recorded in May. There were, however, 72 T200 pairs and 40 T100 pairs intact for analysis. Average height of the T200 seedlings was 36 cm and the average height of controls was 25 cm. In the T100 treatments, average height of seedlings with pads was 25 cm and 21 cm without pads. Table 1 shows survival and height by treatments.

A "t" test for paired observations was used to compare the heights of treated versus untreated seedlings. In the analysis of the T200 data, a "t" value of 9.73 at 71 df showed a highly significant difference between the average height of seedlings with pads compared to those without pads. The difference in average heights with the T100 pads was significant at the 0.01 level ("t" value of 3.1 at 39 df).

The difference in average height of controls in the two groups suggests they might be from different populations. However, it is impossible to compare two groups statistically. This difference also might be related to the tree planter. By chance, 70 percent of the T100 pairs were planted by the person with the low survival record. Raw data showed that the average height of controls by planter was 25.6 cm (n=46) and 24.3 cm (n=45) higher survivals and 21.7 cm (n=31) lower survival. These data were based on control seedlings whether or not the treated partner survived.

It is interesting to note that the average height of the T100 seedlings is the same as that of T200 controls. Grass growing through the T100 pads suggests there may have been a competition factor with this type of pad. However, all of the control seedlings were growing in grass, and an analysis of the T100 treatment showed a significant difference between heights of seedlings with pads and controls. Therefore, it appears that height might also be related to planter.

Table 1.--First-year survival and height of loblolly pines treated with T100 and T200 excelsior pads.

Treatment	No. seedlings planted	Percent survival	Average height (cm)
T100 pads	99	61	25
Control	99	61	21
T200 pads	102	83	36
Control	102	81	25

The cost of an established control seedling for the two "better" planters, if we can assume a seedling is established at the end of one growing season, was 25 cents. For the other planter, it was 33 cents. Thus, it would cost $40 more per acre to obtain 500 established seedlings using the third planter. Add to this, lost volume due to a slow start and the long-term financial loss could be substantial. In this study, the cost of a 1-year established T100 seedling was $4.17 compared with $3.79 for a T200 seedling.

Precipitation during the 1988 growing season was far below normal. Monthly rainfall totals and departures from normal (NOAA 1988) were: April: 2.70 inches, dep. -0.89; May: 2.98 inches, dep. -0.88; June: 2.31 inches, dep. -1.51; July: 4.56 inches, dep. +0.10; August: 1.90 inches, dep. -1.78. Thus, reduced moisture no doubt placed the seedlings under additional stress.

Conclusions and Discussion

Neither type of pad had much effect on seedling survival. However, survival was strongly influenced by the ability of the tree planters. This shows that even under adverse conditions (planting on minesoil and abnormally dry weather), tree seedlings have a much better chance of becoming established if they are handled properly.

The pads did have a positive effect on seedling growth, the T200 pads showing the strongest influence. The geotextile fabric in these pads retarded weed growth and conserved moisture that resulted in an average additional height growth of 11 cm.

On the basis of early results obtained in this study, the T200 pads show an advantage over both T100 pads and control seedlings in enhancing height growth. The cost of these pads, however, must be considered for large-scale plantings. They appear to be better adapted to landscape use than reforestation.

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WOODLAND RECLAMATION WITHIN THE MISSOURI BREAKS IN WEST CENTRAL NORTH DAKOTA[1]

by

David J. Nilson[2]

Abstract. Surface mining in the Missouri Breaks requires the removal of deciduous woodlands associated with drainages that flow intermittently toward the Missouri River. Reestablishing these woodlands requires the use of reclamation techniques that maximize plant available water. Grading, soil handling, site selection, plant material and condition, and proper installation and management operations are important to woodland establishment and survival. Survival data and reproductive capabilities of reestablished woodlands provide some insight into whether or not a stand will become self-perpetuating woodland system. Data collected from tall shrub reclamation study sites established between 1982 and 1984 show initial survival has varied from 54 to 78 percent. However, mean stem densities of shrubs increased 150-375 percent by the end of the third growing season. During the 1988 field season, mean stem densities were within 25 percent of the mean recorded in undisturbed sites.

Additional key words: Woodland reclamation, hardwood draws, reforestation.

Introduction

Surface mining in the Missouri Breaks in west central North Dakota requires the removal of native woodlands known locally as "woody draws" and prairie woodland thickets. These woodlands are associated with mesic sites along drainages that flow intermittently toward the Missouri River. Woody draws are important, not only to a variety of wildlife species, but also to livestock where they provide protection during periods of extreme weather.

Data presented in this paper are from the Glenharold Mine (GHM) which is owned and operated by Basin Cooperative Services, a subsidiary of Basin Electric Power Cooperative. For evaluation and permitting purposes, native woodlands are grouped according to lifeform as low shrub, tall shrub, and mixed deciduous plant communities. These woodlands are distributed across the mine covering approximately 10 percent of the coal reserve area. Although most woodlands have developed along drainages, woody vegetation is not limited to this site. Prairie woodland thickets containing a few or several species, including trees, are distributed across the landscape primarily on north and east facing slopes. Shrub species in order of abundance include chokecherry (Prunus virginiana), silver buffaloberry (Shepherdia argentea), serviceberry (Amelanchier alnifolia), hawthorn (Crataegus rotundifolia) and American plum (Prunus americana). The dominant low shrub species is western snowberry (Symphoricarpos albus) Other common low shrub species include woods rose (Rosa woodsii) and silverberry (Elaeagnus argentea).

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Where trees are present, green ash (Fraxinus pennsylvanica) is common followed by American elm (Ulmus americana) and to a lesser extent box elder (Acer negundo). Cottonwood (Populus deltoides) and willow (Salix spp.) occur sporadically adding to structural diversity. Aspen (Populus tremuloides) are site specific occurring in clumps or thickets in the vicinity of water bearing strata.

Soil

Soil resources typical of wooded draws were described by Richardson (1979) and summarized below. In general, these soils are representative of non-wooded prairie soils in the region. Richardson described uplands as Typic and Pachic Haploborolls where Amor, Temvik, Parshall and Sen soil series are common. These soils are some of the most productive on the mine. Where concave landforms are present, upland prairie thickets of snowberry, woods rose, silver buffaloberry and silverberry are common. The shoulder and upper backslope soils of wooded draws are Ustorthents and typically represented by the Cabba soil series. Further downslope where soil depths increase and landform is more concave, soils were classified as Lithic and Entic Haploborolls. At this location the Werner soil series is common.

History

Following the enactment of the Surface Mining Control and Reclamation Act in 1977 (SMCRA, P.L. 95-87), opposition to mining wooded draws increased. Woodland reclamation plans in existing permits consisted of the installation of shelterbelts and the use of traditional shelterbelt technology. This was considered inadequate from a wildlife habitat standpoint. Approval of permit applications became contingent on mining plans that avoided woodlands of exceptional quality as they were considered irreplaceable. Additionally, the ability to replace woodlands with a diverse self-perpetuating woodland system capable of sustaining comparable wildlife populations was vigorously contested. Without resolution, this conflict threatened the coal supply to the Leland Olds Power Station. To resolve this conflict, it was necessary to develop and evaluate new reclamation technology and demonstrate its capability to mitigate woodland/wildlife losses. Concurrently, it was necessary to initiate a wooded draw ecological study to develop a better understanding about "woody draw" ecosystems. This required a multi-disciplinary approach involving biologists, ecologists, soil scientists and hydrogeologists, as well as oversight by the Public Service Commission and by state and federal wildlife agencies. The results of this two pronged approach was used to develop a new reclamation plan for areas mined following the enactment of SMCRA.

One of the first woodland reclamation study areas established under this plan was the Glenharold Mine Wooded Draw Demonstration Site (WDDS) in 1978. In addition to the development and application of operational procedures, other factors were evaluated including potted versus bare-root stock, vermeer spade transplants, soil depth effect, slope, aspect and stand position importance. Initial growth and survival data were reported by Williamson and Wangerud (1980).

The results of the wooded draw ecological study were compiled by Williamson et al. (1982) in an unpublished report submitted to the North Dakota Public Service Commission. In summary, three environmental factors emerged from this study that were important to the presence of woody vegetation. These included:

1. Landform/shape (geomorphology).
2. Aspect.
3. Shallow water table outcrops.

Of these, geomorphology and aspect directly affect the amount of plant available water and consequently the presence or absence of woody species. The most advantageous combination of these factors for both woodland establishment and development is a north, northeast or east facing slope with a concave surface profile. Of these two variables, landform is the most important for two reasons. First, although woodland areas are more common on north and east facing slopes, some shrub species are present on drier south and west facing slopes where the surface configuration is suitable (Richardson 1979, Mack 1981). Second, north and east facing slopes with convex surfaces do not have woodland plants unless underlain by a shallow water table, or fed by a spring or seep from a higher elevation. Generally, where site factors altered the moisture regime, native woodlands were likely to occur.

Woodland Reclamation Plan

The GHM woodland reclamation plan evolved from the installation of shelterbelts using traditional tree planting equipment and bare root stock in the mid 70's to the use of containerized stock and hand-held motorized coring equipment in 1980. Planting densities were increased from approximately 1,500 plants/ha (600/ac) to 12,000/ha (4,800/ac) to compensate for expected losses during the first few years. These densities were later changed, however, as ongoing monitoring studies in the wooded draw demonstration site indicated that reproduction of major shrubs, via suckering, tripled and in some cases quadrupled stem densities from the number initially planted. American plum suckers, for example, were found up to 1.5 m from the parent plant after 5 growing seasons (Nilson 1983). Because of this reproductive capability, a lesser number could be installed and still meet density standards. Also, it was obvious that the cost of containerized stock combined with labor intensive planting methods needed to be re-evaluated. In 1982, a revised reclamation plan was developed which mechanized the planting process and radically reduced reclamation costs without sacrificing reclamation quality. This plan called for the installation of bare root stock using a conventional tree planter and crew contracted through the Soil Conservation Service. Using this equipment, all shrubs are installed on approximately 1.25m centers (4 ft.) for a total planting density of 6,670 plants/ha (2,700/ac). Following shrub establishment, tree species are installed by hand in the most favorable microclimates. Using this method, planting and plant material costs were reduced by 75 percent. Also, it allowed for the installation of 8,000 to 10,000 plants per day using a 3 man crew (one tractor operator and two planters). At this rate, an annual replacement acreage of 10 ha (25 ac) could be planted in 7-9 days.

Planting Mixtures

Three planting mixtures listed in Table 1 are typical of those used to replace deciduous woodland, tall shrub and low shrub plant communities. Extant species do not occur in the area but are present along the Missouri River or have the capability to inhabit the area. These species are added as an experimental component to enhance wildlife habitat characteristics.

Planting Sites

Based on research conducted at the Glenharold Mine, and data collected from reestablished woodlands, it was concluded that those factors important to the success of native woodlands are also important to reclamation woodlands. Proper surface configuration and aspect are major factors to consider in planning and developing a post-mine topography. At the GHM, prime woodland sites are selected following the normal grading process. If a sufficient number and acreage do not occur, special grading operations are conducted. These include the excavation of concave surfaces on slopes that face north, east or northeast. Typically, planting sites vary from .1 to 4 ha (.25-10 ac) depending on surface configuration and general topography. The majority of planting sites are along drainage bottoms, side-slopes or sites simulating natural escarpments.

Soil Management

Generally, no special soil removal or replacement operations are included in the woodland reclamation plan. As part of the overall reclamation plan however, special soil removal operations are conducted to salvage subsoils that are physically superior and capable of improving chemical and physical characteristics across an entire tract. Chemical criteria set by the PSC to determine whether or not topsoil and subsoil is suitable are well within the tolerances for establishment and growth of native trees and shrubs used in reclamation. Also, no special surface field operations such as deep tillage or ripping, are conducted to minimize compaction and improve soil water storage capabilities.

Soil Amendments

Site preparation includes the incorporation of two types of fertilizer. The first is a slow release nitrogen (38-0-0) which is applied at a bulk rate of 280 kg/ha (250 lbs/ac). This fertilizer is slow to react with water and is included to provide a source of nitrate nitrogen over a period of several years. The second fertilizer application includes phosphorus and soluble nitrate nitrogen. Both fertilizers are tilled into the soil to a depth of 15-20 cm (6-8 in). Where the topsoil or first lift material is less than 15 cm, fertilizer is spread following the distribution of subsoil. Application rates are based on soil tests and historical soil test data to ensure minimum nitrogen/phosphorus levels of 56 and 168 kg/ha (50-150 lbs/ac) respectively.

Table 1. Typical reclamation planting mixtures used to replace mixed deciduous, tall shrub and low shrub plant communities.

	Deciduous Woodlands		Tall Shrub		Low Shrub	
Species	Plants/ha	% Comp.	Plants/ha	% Comp.	Plants/ha	% Comp.
Tree Layer (TL)						
Willow	62	5				
Boxelder	198	15				
Green ash	802	60				
Cottonwood	198	15				
Bur oak (ES)	37	3				
Hackberry (ES)	37	3				
TOTAL TL	1,334	100				
Tall Shrub Layer (TS)						
Native plum	1,062	25	1,087	20		
Silver buffaloberry	556	13	1,087	20		
Serviceberry	803	19	543	10		
Chokecherry	1,062	25	1,198	22		
Round-leaved hawthorn	531	12	1,087	20		
Red osier dogwood	247	6	272	5		
Bristly gooseberry	0		161	3		
TOTAL TS	4,261	100	5,435	100		
Low Shrub Layer (LS)						
Silverberry	531	50	371	30	1,335	20
Woods rose	272	25	494	40	1,335	20
Snowberry	272	25	371	30	4,000	60
TOTAL LS	1,075	100	1,236	100	6,670	100

ES - Extant Species

Planting Schedule

All shrub species are installed in the early spring as soon as field conditions permit. Dates have varied over the past nine years from mid-April to early June, depending on the advent of spring conditions. Generally, planting is done into sites prepared the previous year to take advantage of soil water recharge over winter. If spring soil temperatures warm sufficiently to germinate a weed crop prior to planting, areas are sprayed with a non-selective herbicide (glyphosate). Tree species are installed by hand following mulching operations but in most cases they are installed the following year to facilitate weed control operations during the first year.

Erosion Control

To avoid competition for soil moisture, neither a temporary nor permanent herbaceous cover is seeded. Instead, all woodland sites are mulched at a rate of 11,200 kg/ha (5 ton/ac) to control erosion and to preserve soil moisture levels. A slough hay mulch is spread over the area to depths of 5 to 10 cm (2-4 inches) using a big bale mulcher. To avoid vehicle rutting and to maintain operational stability, a four-wheel drive tractor with dual wheels is used to power the mulcher. If over winter soil water recharge is deficient, mulching may be delayed until after the first sufficient rain following planting.

Management

Broadleaf weeds and perennial grass control may be necessary for 2 to 3 years following installation. The heavy mulch application can reduce weed populations the first growing season and has at times precluded the need for any weed control. Weed control in subsequent years is accomplished using both pre-emergent and post-emergent herbicides. Glyphosate is used prior to and following planting if necessary. After installation, it is applied using a hand held nozzle and hose attached to a mobile spray unit. Chemical is applied under low pressure during days of very little wind. Since windy days are the rule rather than the exception in North Dakota, more areas are being treated with dichlobenil (Casoron 4-G) which inhibits herbaceous root and shoot growth. Dichlobenil is a granular herbicide applied during late fall at a rate of 140-170 kg/ha (125-150 lbs/ac) using a broadcast fertilizer spreader.

Woodland Reclamation Success

As of the end of 1988, approximately 60 ha (@150 ac) of woodlands have been reestablished on reclaimed land at the Glenharold Mine. To facilitate advancement in woodland reclamation design and ensure performance standards are met, reclamation areas are monitored on an annual basis. Changes in survival, diversity and density, have been observed over the past 10 years. Data in this paper are presented for study sites WDDS2, Section 16 and Section 19. The first two were planted in 1982 while the latter was planted in 1984. The relative composition based on 1988 data are presented in Table 2.

Table 2. Relative composition of major species on woodland reclamation study sites in 1988.

Species	WDDS2	Sec.16	Sec.19
	------Relative %-------		
Serviceberry	0.0	0.0	3.3
Red-osier dogwood	10.1	1.4	7.6
Silverberry	0.0	9.6	0.0
Amer. plum	28.7	29.0	18.2
Chokecherry	30.4	19.4	5.6
Woods rose	11.3	13.9	64.8
Silver buffaloberry	17.0	24.5	0.0
Green ash	2.2	2.0	0.0
Other	.3	.2	.5
	-------Stems/ha--------		
Total	31,125	28,100	33,500

Although trees are present, both WDDS2 and Section 16 resemble tall shrub plant communities because of their age. Also, these areas have similar species composition and stem densities. Plant community comparisons using similarity coefficients show stem densities of species common to both areas to be 78% in 1983, the year following establishment. This similarity declined to 57% in 1984 but increased to 79% by the end of 1988. When compared to study site

Section 19, WDDS2 and Section 16 had similarity coefficients of 36 and 47% respectively.

Reproductive capabilities of tall and low shrub species on these sites provide encouraging evidence that self-perpetuating woodlands are possible. Stem density data collected between 1983 and 1988 show a mean annual growth rate of approximately 45% through 1988 for study sites WDDS2 and Section 16 (Figure 1). The Section 19 site had an annual density growth rate of 57%. This is attributed to the dominance of woods rose which suckers prolifically. As a consequence of these growth rates, the number of stems per hectare ranged from 28,100 (11,375/ac) in Section 16 to 33,500 (13,550/ac) in Section 19 by the end of 1988. These densities are within 25 to 30% of the mean stem density of tall shrub species in native tall shrub communities across the mine.

Topographic and surface variability, aspect and soil water differentials all contribute to wooded draws that are non-uniform and structurally complex. This vertical and horizontal diversity contributes significantly to wildlife diversity and are attributes that are real in terms of designing and developing replacement woodlands. As observed in undisturbed sites, woodland reclamation areas developed since 1978, show density and height variation depending on site characteristics. Figure 2 demonstrates mean stem density differences between lower, middle and upper slope positions over time on WDDS2. Height data of major species collected in 1985 show similar differences (Figure 3).

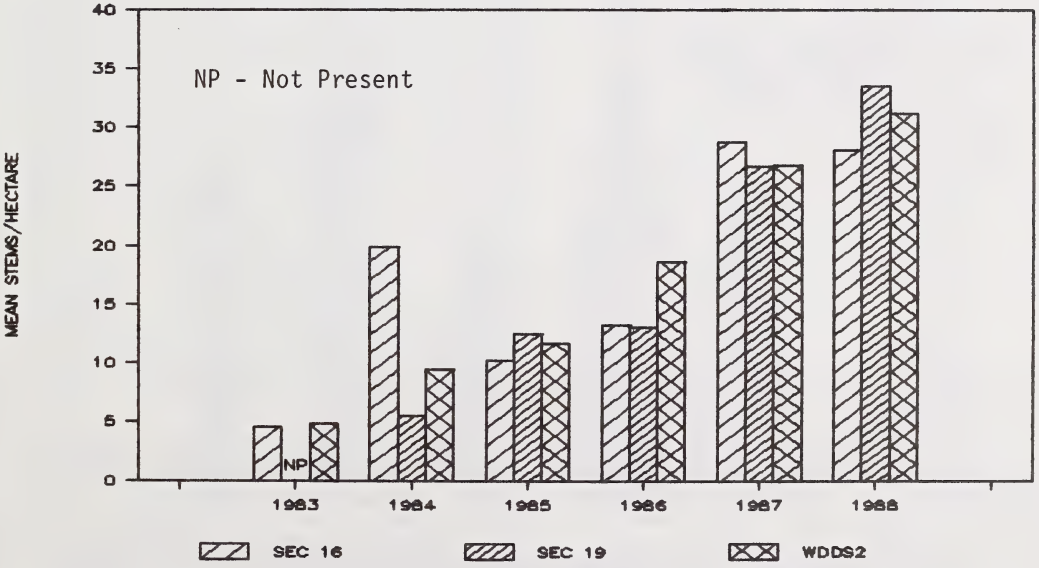

Figure 1. Changes in mean stem densities (thousands) over time on 3 woodland reclamation study sites on the Glenharold Mine.

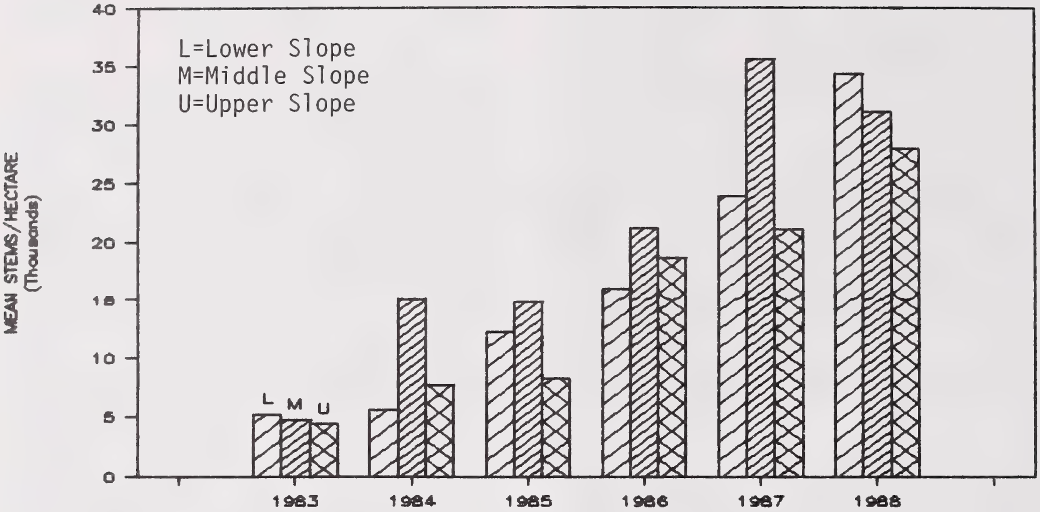

Figure 2. Changes in mean stem densities over time by slope position in the Glenharold Mine Wooded Draw Demonstration Site 2.

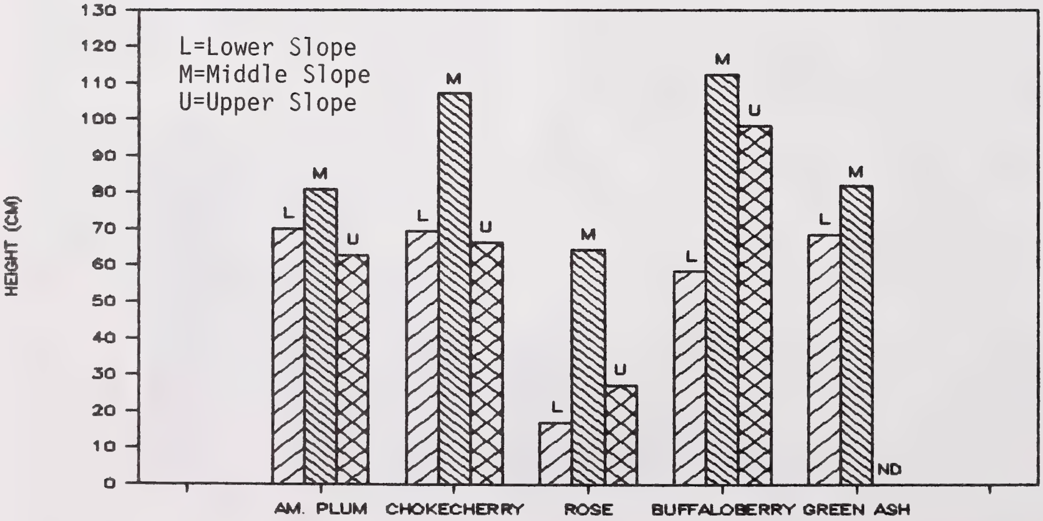

Figure 3. Effects of slope position on mean height of major species on study site WDDS2 (1985 data).

Effect of Soils on Woody Vegetation

Native woodlands occur over a wide variety of soils with often adverse physical and chemical soil characteristics. Shrub communities have been observed on shallow Cabba soils underlain by scoria to sodium affected Daglum and Rhoades soils in drainage bottoms and foot slopes. Richardson (1979) recognized the lack of correlation between soil type and properties and the presence of woody vegetation except with respect to landscape position and shape. Woodland vegetation can be present or absent from the same soil series and slope position depending on whether or not the surface is concave or convex.

A poor relationship between growth and survival and soil depth also is evident on reclamation woodlands established since 1978. Williamson and Wangerud (1980) found survival and growth on 30, 75 and 150 cm (12, 30 and 60 in) soil depths to be highest on 30 cm deep plots. Also soil depth did not cause total stem densities to differ in WDDS2 and Section 16 study sites. Approximately 45 cm (18 in) of soil was respread over sodic spoil (SAR > 25) in WDDS2. In contrast, over 90 cm (36 in) was respread over good quality spoil (SAR < 10) in the Section 16 site. Despite this difference, total stem densities were similar over the past four growing seasons (Figure 1).

Weather Effects & Survival Notes

Precipitation and temperature data are collected from on-site weather stations and compared with long term (20 years) data from the National Oceanic and Atmospheric Administration (NOAA). The long term average annual precipitation is 42.9 cm (16.9 in) varying from 29.9 cm (11.8 in) to 61.2 cm (24.1 in). Approximately 70% falls during May through September and almost half of this occurs during a period from May through July (Figure 4). GHM records show the mean May through September precipitation to be 25.6 cm (10.1 in) slightly less than the 20 year mean of 29.7 cm (11.7 in). Mean precipitation over the last 5 years is also less than the long term average.

Long term data from NOAA show years of high precipitation are often characterized by below average temperatures while years of low precipitation have higher temperatures. Figure 5 illustrates the relationship between total May through July precipitation, relative to long term averages and the number of days temperatures exceeded 32° C (90° F). In 1980 and 1988 when total May through July rainfall was 54 and 63% of normal, first year survival was generally less than 50% and as low as 14% on some sites. In 1981 and 1984 when May-July precipitation was similar, overall survival was well over 70%. Where the 1980 and 1988 years differ from 1981 and 1984 is that temperatures were higher during the critical spring and early summer period. Also, the lack of fall moisture left subsoil moisture levels in short to very short supply prior to planting.

In comparison, these periods demonstrate the role of temperature in ameliorating precipitation deficiencies. It also points out the importance of selecting slopes of a north, northeast or east aspect where total day time exposure to direct sunlight is less. In 1984 and 1988, stem densities on these study sites increased even when May-July precipitation was below normal.

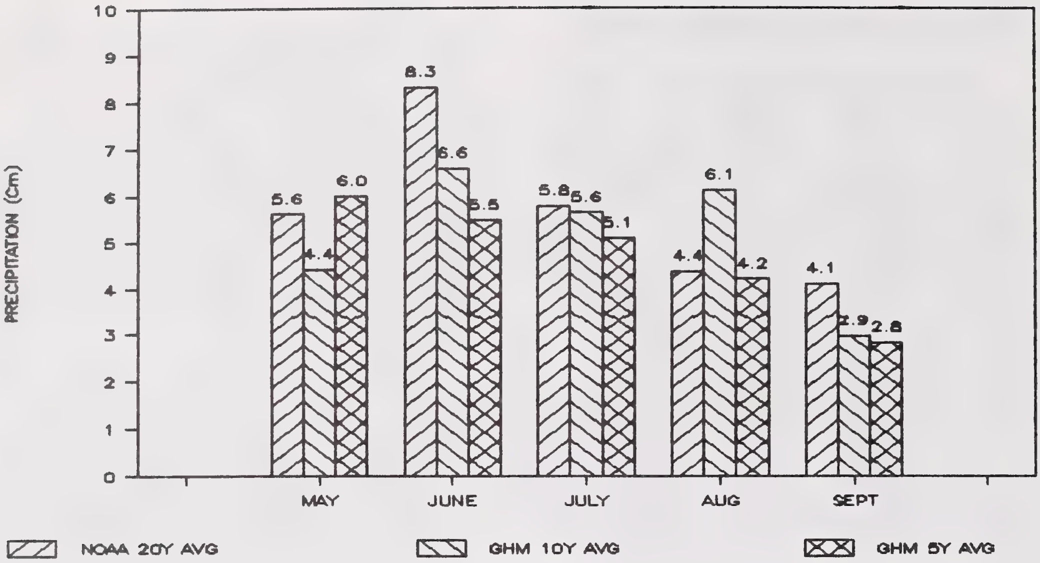

Figure 4. Five and ten year average May-September precipitation received at the Glenharold Mine relative to the long term average.

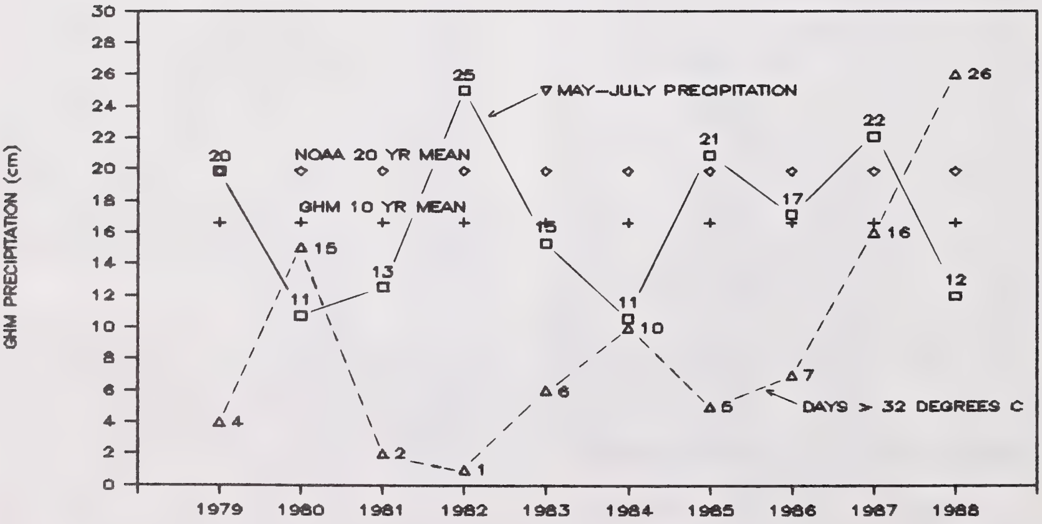

Figure 5. Changes in total May-July precipitation relative to the number of days where temperatures exceeded 32 degrees C (90 degrees F).

Summary

Colonization of native grasslands by pioneer shrub species such as snowberry and silverberry are initial stages of a successional pattern leading to a climax plant community. If conditions develop which create a more mesic microclimate, then tall shrub and tree species will become established.

Many environmental factors important in ecological succession in native woodlands are also important to restored woodlands. Basic to woodland reclamation success is the selection and development of sites where soils water levels are augmented by landform and aspect. On these sites, a high density woodland planting can insure adequate survival numbers and reproductive capabilities of remaining plants can quickly increase stem densities. This in turn alters the microclimate providing more favorable conditions for successional processes to occur. The final product is a self-perpetuating woodland system with many attributes important to wildlife inhabiting the Missouri Breaks.

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USE OF AN ORGANIC FERTILIZER IN REVITALIZATION OF PROTECTIVE FORESTS IN THE AUSTRIAN ALPS AFFECTED BY FOREST DECLINE [1]

by

Gerhard Glatzel, Klaus Katzensteiner, Hubert Sterba
and Kurt Haselwandter [2]

Abstract. BIOSOL*), an organic fertilizer based on sterilized and dried mycelial residue from commercial antibiotic production, was tested as an alternative to mineral fertilizers in field experiments designed at revitalizing Norway spruce stands (Picea abies) affected by forest decline in Lech, Vorarlberg. Basal area increment responded positively and significantly to both mineral fertilizer and BIOSOL. Foliar nutrient levels increased only slightly and no major changes in soil microbial activity or mycorrhizal status were observed. Thus fertilization with moderate amounts of fertilizer seems to be a safe method to increase tree vigour without dramatically changing site parameters. Both fertilizer treatments were not sufficient to increase the production of viable seeds to an extent desired for improved regeneration of the stands. Due to its slow release characteristic BIOSOL is considered superior to soluble inorganic fertilizers for high elevation sites with soils of low sorption capacity and high leaching potential.

*)registered trademark of Biochemie Ges.m.b.H., Kundl, Austria

Additional Key Words: protective forests; forest decline; soil amelioration.

Introduction

The decline of protective forests in the Alps is a pressing problem. In many areas these forests were grazed by cattle, sheep or goats for centuries. In addition to browsing and trampling of young trees, such practices caused mineral nutrient depletion, soil compaction and injury to main roots. High game densities and the current problems with air pollution are aggravating the situation and many Alpine forests are in poor condition.

The forests of the well known tourist resort LECH in the Arlberg region of Western Austria, are typical examples of such declining forests. These forests are still used for grazing or as a refuge for livestock when early snow hits the alpine pastures. Most forests exhibit extremely imbalanced age structure. Regeneration has been virtually eliminated for decades or even centuries and thus old trees dominate. Many of the old trees are affected by root- and heart-rot and by mineral deficiencies due to the steady removal of biomass by grazing. As these forests decline and loose their protective function against avalanches and soil erosion, major efforts have to be undertaken to insure their revitalization and regeneration.

Natural regeneration is considered the most desirable method of regenerating these forests, mainly because the genetic information of the local tree populations is to be conserved. The poor vitality and the progressive deterioration of the old trees, which rarely produce viable seed, make this goal unattainable in many cases. A means to temporarily restore the vitality of these ageing stands and to carry them through the regeneration period are, therefore, much sought after.

The experiments in LECH are designed to test the use of fertilizer to improve the mineral nutrition of the trees and thus enhance vitality and seed bearing capacity. As soluble mineral fertilizers are subject to significant leaching losses at high altitude - high precipitation situations with a vegetation period as short as four months, a slow-release organic fertlizer (BIOSOL), based on mycelial biomass from commercial antibiotic production, was included. In pot experiments (Glatzel & Fuchs 1986) this fertilizer had shown very positive effects on root growth of Norway spruce (Picea abies).

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[1] Paper presented at the symposium "Reclamation, a Global Perspective", Calgary, Alberta, Canada, August 27-31, 1989.

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Materials and Methods

Experimental Sites

LECH is a well known skiing resort in Vorarlberg, the westernmost province of Austria. The elevation of the experimental area is 1550 to 1600 m. The mean annual temperature is 3.8 C, the mean annual precipitation 1500 mm, the mean annual duration of snowcover is 193 days and the cumulative snow deposition amounts to 780 cm per year. Geologically the area belongs to the northern Calcareous Alps. Moraine till and talus material of dolomite, limestone and shale comprises the parent material for soil formation at the two experimental sites Lech 5 and 6. Both sites are on the lower and only moderately steep part of mountain slopes originating above timberline at more than 2000 m elevation and leveling off at the valley floor at 1530 m. The aspect of Lech 5 is SSE while that of Lech 6 is NE. Due to the uneven micro relief and the disturbances from grazing, soil properties show extreme variation within small areas. Generally rendzina soils dominate but intermixing with shallow brown earths is common, especially at Lech 6. On stony or gravelly ridges the soil is well drained and rather dry, while wet soils with peaty O-horizons dominate in small dells. $pH_{(KCl)}$ is between 4.6 (Lech 5) and 5.4 (Lech 6) in the A-horizon and increases to about pH 7 at the C-horizon boundary. As a consequence of a long history of grazing by cattle, nutrient pools in the soil are depleted. Soil nutrient contents are generally lower at Lech 5 due to its higher content of rocks and gravel and due to heavier grazing at this warmer, more exposed site.

Forest Stand Characteristics

Open stands with small clumps of trees characterize both sites. There are about 270 to 280 trees per hectare. The estimated mean age is more than 200 years. The standing biomass (wood plus bark) is 290 m^3 at Lech 5 and 520 m^3 wood with bark at Lech 6. The visual assessment of tree vitality, based on parameters such as needle loss and yellowing (Pollanschütz 1985), gave a mean crown index of 1.6 which indicates above average needle loss.

Foliar analysis (table 1) of needles harvested from the 7th whorl indicated nitrogen deficiency on both sites and, in addition phosphorus deficiency at Lech 5.

Table 1. Foliar nutrient content in 1985 before treatment (new needles from the 7th whorl, mean values from 18 (Lech 5) and 27 (Lech 6) trees)

Element	Content $mg.g^{-1}$ dry matter Lech 5	Lech 6
Nitrogen	10.40	12.20
Phosphorus	1.45	1.58
Potassium	7.35	6.29
Calcium	3.97	3.36
Magnesium	1.53	1.21

Experimental Design

Because of the extreme heterogeneity of the soils and stands, conventional plot experiments were not possible. Therefore tree clumps of similar density were singled out and used as experimental units. Fertilizer was applied in a circular area with a diameter of 30 m around the central tree. Measurements were taken from the central tree or from the next neighbours when the central tree was damaged by snow, storm or lightning during the experiment.

The following treatments were tested

a) Control
b) Mineral N-P-K-fertilizer (15:5:18, P and K as oxides) chloride free, with magnesium (3 % MgO) and trace elements
400 $kg.ha^{-1}$ were applied both in 1985 and 1987
c) BIOSOL
1000 $kg.ha^{-1}$ were applied both in 1985 and 1987

The number of replications was 6 at Lech 5 and 9 at Lech 6.

Table 2 gives the composition of the organic fertilizer BIOSOL, an organic fertilizer based on mycelial biomass from commercial antibiotic production by BIOCHEMIE Ges.m.b.H. - Kundl, Austria. Residual antibiotic activity was destroyed by heat treatment. Because part of the nitrogen is bound in chitin it is only slowly released by microbial action in the soil. BIOSOL is also especially rich in siderophores ("iron carriers") and can therefore improve trace element nutrition (Haselwandter et al.1988).

Table 2 Composition of the organic fertilizer BIOSOL

Parameter	Content (percent)
Organic matter	70
Organically bound N	5 - 6
Soluble N	less than 5
P (as P_2O_5)	1 - 2
K (as K_2O)	3 - 4
Mg (as MgO)	0.5 - 2.5
Ca (as CaO)	3 - 5
Antibiotic activity	below detection limit

Measurements and Analyses

Diameter growth: by means of permanent dendrometers.
Crown vitality: by visual inspection (Pollanschütz 1985)
Cone production: counting with binoculars
Seed Yield and Viability: mechanical or heat seed extraction, seed testing by X-ray analysis.
Mineral Nutrition: foliar analysis on current and older needles from the seventh whorl.
Soil Analysis: conventional soil analysis supplemented by biochemical analysis. Microbial biomass by the method of Anderson and Domsch (1987).
Mycorrhiza: survey of mycorrhiza types and subsequent counting of mycrrhizal root tips of representative root samples.

Results

Tree Growth

Because the diamaters of the study trees varied substantially, and basal area increment is correlated with diameter, analysis of covariance was used to reduce the error due to variances in initial stem diameter. Table 3 shows the annual increments in basal area per tree.

Table 3 Mean annual increment in cm^2 basal area per tree

Site Year	Treatment Control	 BIOSOL	 Mineral Fertilizer
LECH 5			
1986	17.4	19.7	19.8
1987	6.6	11.3	12.8
1988	16.9	24.5	22.0
86-88	13.6	18.5	18.2
LECH 6			
1986	27.8	35.1	29.9
1987	14.8	21.4	18.8
1988	19.9	32.5	27.1
86-88	20.8	29.7	25.3

The increment was generally much smaller at Lech 5 due to its poorer soil. In 1987 an extremely cool summer led to a marked setback in growth. Both fertilizer treatments had significantly (at 1 percent level) increased growth by 33 percent over a three year period. The difference between the BIOSOL and the mineral fertilizer treatment was not significant at the 5 percent, but significant at the 10 percent level.

Crown Vitality

Even though the visual appearence of crowns in terms of color and needle density on new shoots had improved, these changes were not statistically significant (at the 5 percent level). Extreme variation between individual trees was the main reason that the method of using visual symptoms was inadequate in an experimental design where only one tree was the experimental unit. This method gives much better results in conventional designs with more observational units per replication.

Foliar Nutrient Contents

Figure 1 shows the mean values for the foliar nutrient levels in the current year's needles from the 7th whorl for the years 1986 and 1988. These data show that the fertilizer treatments did not induce pronounced changes in the foliar nutrient levels. As tree growth had significantly increased, it can be assumed that extra nutrients from the fertilizer enabled the trees to increase their canopy mass rather than their foliar nutrient content. It is extremely unlikely that the very small changes in the mineral content of the needles could have an effect on hardiness or resistance against disease or insects.

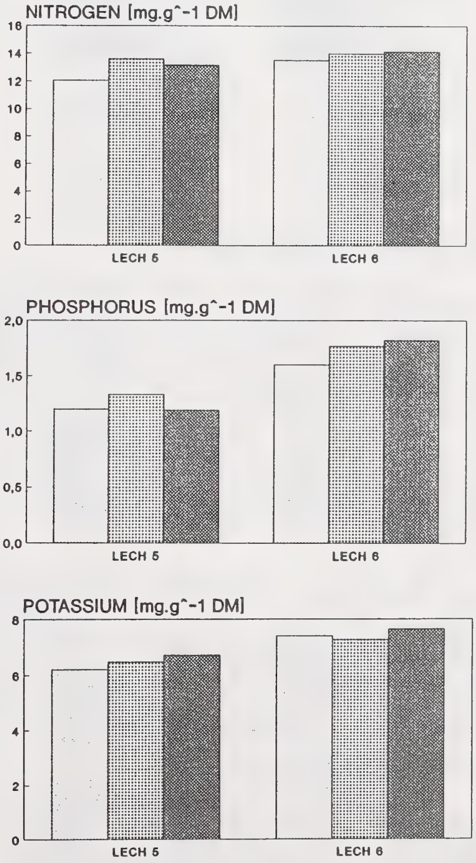

Figure 1 Foliar nutrient content ($mg.g^{-1}$ dry matter of current year's needles; mean for the years 1986 and 1988)

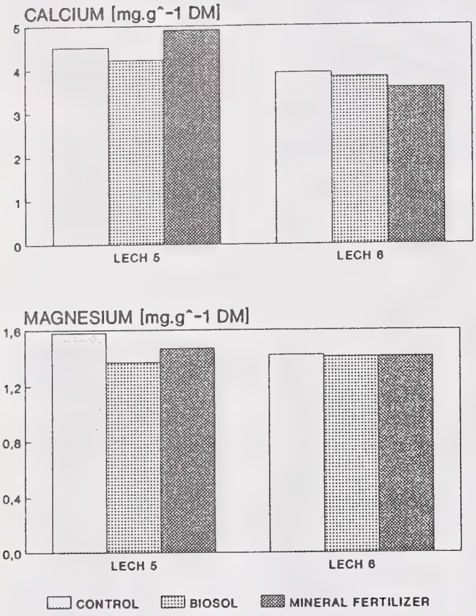

Figure 1 continued

Soil Biology and Mycorrhizae

Respiration of soil samples collected from the various treatments at Lech 6 in 1988 showed no significant differences under laboratory conditions. Microbial biomass as determined by the method of Anderson and Domsch (1987) in soil samples from Lech 6 collected in July and September 1988 was similar for all treatments in July but showed a statistically significant decrease at the fertilized sites in September. Possibly the easily degradable material was utilized early in the vegetation period and that microbial populations broke down later in the season.

The counts of mycorrhizal root tips of light color, which are usually considered to be a measure of functional mycorrhizal infection, for root samples taken from Lech 6 in 1987 and 1988 showed large variation. Statistically significant effects of the fertilizer treatments on mycorrhizal infections could not be detected despite fourfold subsampling per treatment unit.

Seed Production and Fertility

During the first three years of the experiment less than half of the trees produced a moderate cone crop. There were no treatment effects. Figure 2 shows the length of the cones and the percentage of viable seeds from X-ray analysis from the 1988 harvest. In Lech 6 BIOSOL treatment had a statistically significant effect on cone length. Cone diameter and cone mass were not significantly changed. The percentage of viable seeds was slightly higher in the BIOSOL treatment at both sites and and lower in the mineral fertilizer treatments. The effect was just not significant (5 percent level).

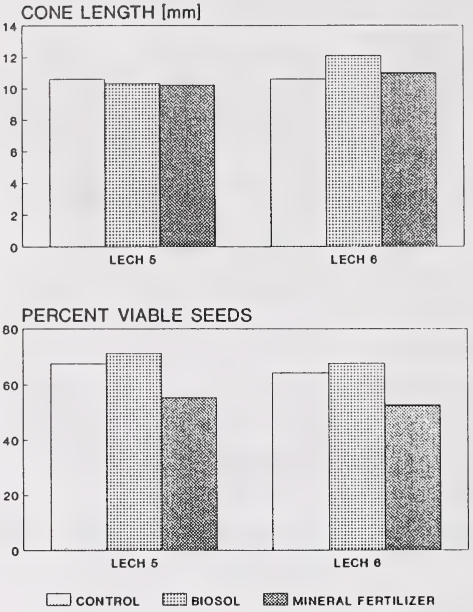

Figure 2 Cone length and percentage of viable seeds from the 1988 seed crop

Discussion

After three years the experiments in Lech have shown that Norway spruce (Picea abies) trees of poor vigour growing in high altidude protective forests can be revitalized by improving mineral nutrition. Most biometric variables, especially visual assessment of tree crown status, proved to be inadequate for estimating tree vigour when an individual tree represents the treatment unit. The most reliable variable was basal area increment measured by permanent dendrometers. Fertilizer treatments increased basal area growth by 33 percent. The result was statistically significant.

Foliar nutrient levels at the 7th whorl were only slightly increased by fertilization. Improved growth seems to result more from additional foliage rather than from higher nutrient levels in the existing foliage. The frequently expressed concern that fertilizer application at high altitudes may decrease hardiness or increase susceptibility for deseases and pests seems not warranted under our treatment regime. Soil biochemical analyses and mycorrhizal counts gave no indication of dramatic changes due to fertilizer application. At these nutrient depleted sites additional nutrients are rapidly incorporated into the tree and herbaceous vegetation and into soil sinks. Based on these results a slightly higher fertilizer dosage is recommended for future trials.

Cone production was not affected by the fertilizer treatment. The value of increased flowering or cone production would be doubtful for a wind pollinated species under a situation where only some stands are treated. Even though cone length and the yield of viable seeds was slightly higher in the BIOSOL treatment, it appears that moderate and local fertilizer addition are not sufficient to bring a dramatic increase in seed production of declining high elevation Norway spruce stands.

The organic fertilizer BIOSOL proved to be at least equal in effect to an inorganic fertilizer when an equivalent amount of nitrogen is applied. The main advantage of the organic fertilizer is its slow release of nitrogen, which makes overdosing and losses to the ground water from leaching less likely.

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Industrial and Urban Sites

Session Chairman: S. Abboud

THE APPLICATION OF GERMINATION TESTS TO REVEGETATION OF PHOSPHO-GYPSUM TAILINGS: Preliminary Findings[1]

by

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Abstract. Reclamation of phospho-gypsum tailings has become of concern due to the quantities of tailings involved, potentially toxic contaminants of the tailings, and the slow rate of natural revegetation. Preliminary results of germination tests on Alberta tailings are presented. These were used to examine the phytotoxicity of the tailings, the effectiveness of lime and soil amendments, and variation in sensitivity between chosen shortgrass prairie species. Recommendations are then made for future work.

Additional Key Words: Phosphate fertilizer; Reclamation

Introduction

Phospho-gypsum tailings are a by-product of the phosphate fertilizer industry. Phosphate-bearing ore, which has been crushed and beneficiated at the minesite, has been imported to Canada primarily from the Western U.S. and Florida (McBeath 1987).

At the plant site this ore is ground and digested with sulphuric acid to produce phosphoric acid and calcium sulphate (gypsum). The phosphoric acid is then ammoniated to produce ammonium phosphate fertilizer. From 4.5 to 5.2 tonnes of phospho-gypsum tailings are produced for every tonne of phosphoric acid (as P_2O_5) produced (McBeath 1987).

There are approximately 81 million tonnes of phospho-gypsum tailings stockpiled in Canada. About 3.6 million tonnes are being produced annually (Senes 1987), of which 0.8 million tonnes per year are disposed of in watercourses and in the ocean.

In the U.S., over 304 million tonnes of phospho-gypsum tailings are stockpiled, and 30 million tonnes are produced annually (May and Sweeney 1982).

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[1] Paper presented at the conference Reclamation, A Global Perspective, held in Calgary, Alberta, Canada August 27-31, 1989. Publication in this proceedings does not preclude authors from publishing their manuscripts, in whole or in part, in other publication outlets.

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Four phosphate processing plants have been shut down in Canada, at an average age of 20 years (Senes 1987). The seven plants presently in operation (or mothballed) range in age from 20 to 58 years. A number of these may also require decommissioning in the near future.

To date, no phospho-gypsum tailings have been reclaimed in Canada, although several planning and research projects are currently underway. The need for environmentally sound procedures for reclaiming these tailings is critical.

A number of researchers are currently examining possible re-use of these tailings, in products such as agricultural amendment, wallboard and aggregate for road construction. The choice of options is limited, in part, by the nature and concentrations of contaminants, particularly radioactive contaminants, in the tailings. Until these difficulties are overcome, phospho-gypsum tailings will be reclaimed in place.

The first consideration in reclamation planning is to select an appropriate end land use. The reclamation plan must balance desirability of end-point land use with the tailings limitations such that an optimal solution considering human health and safety, economics, social needs and environmental concerns is generated.

Revegetation must be feasible for most end land uses, but the rate of natural revegetation of phospho-gypsum tailings is slow.

In our present research we are attempting to determine what hindrances to revegetation exist, and how to overcome them.

This paper will report on the preliminary findings of germination tests used to select suitable species and amendments for phospho-gypsum tailings revegetation. These tests form one part of a larger study on the reclamation of phospho-gypsum tailings in Alberta.

Tailings Characteristics

The physical and chemical properties of phospho-gypsum tailings present special challenges for reclamation. A detailed assessment of specific tailings is currently underway as part of this study Preliminary findings and data from the literature are summarized below.

The primary constituent of the tailings is gypsum (calcium sulphate), comprising roughly 90% by dry weight (May and Sweeney 1983). Another 8% or so is silicates - sand and clay. The rest will be referred to as contaminants.

The contaminants include radioactive species such as uranium, radium, and their decay products, and heavy metals such as aluminum, iron, arsenic, cadmium, chromium, lead and silver (May and Sweeney 1983). Potential concerns include: toxicity to vegetation, bio-accumulation in the food chain, and health effects such as carcinogenicity.

The low pH of fresh tailings, due to the presence of phosphoric and fluorosilicic acids, inhibits revegetation. Deep rooting zone samples (0-3m) from active ponds show pH values of 2.15 to 3.25 (May and Sweeney 1982). However, ponds which remain inactive show a rise in surface pH over time - a pH rise to 5.5 after ten years has been reported in a Texas pond (surface samples - sampling depth not reported) (Naff 1984).

The tailings used for this study, 0-15cm in depth, showed a pH of about 4.5.

Salinity could affect revegetation success. Tailings measurements performed during this study showed conductivity values in the range of 2.24 to 4.47 mmhos/cm. These levels have been found to reduce yields only in sensitive species (Holm 1978).

In addition, the composition of phospho-gypsum does not appear likely to contain all of the essential nutrients in the required balance to sustain plant growth. This is being investigated furthur.

The physical properties of the tailings which appear to be of concern include the influence of hydraulic conductivity and moisture-holding capacity on water availability for plants. This is of particular concern in arid areas, such as the study tailings site.

Properties such as thermal conductivity and surface color may also affect germination success and growth by influencing the temperature at seed depth (Headdon 1980).

In addition, the tailings tend to form a strong surface crust over time. Although this greatly reduces dusting problems, it may act to inhibit root or shoot penetration.

The properties of the tailings must also be considered in planning revegetation operations. For example, the low shear strength of these tailings will require use of wide-track revegetation equipment.

Germination Tests

Germination and early growth tests were used to examine the toxicity of phospho-gypsum tailings, the effectiveness of amendments, and variation in sensitivity between species.

The arid climate of the southern Alberta tailings site limited the species chosen for this study to those appropriate for shortgrass prairie. Species were chosen after consideration of: their autecological properties, such as drought resistance, pH, heavy metal and salinity tolerances, forage quality, and methods of self-propagation; success in other reclamation projects; and, commercial seed availability. The general site conditions were taken from a review of literature and field observations. Laboratory analyses are currently underway to obtain more specific information. Based on the preceding considerations, the species listed in Table 1 were chosen for initial germination testing.

Experimental Method

For each species, four different treatments were tested. These were: filter paper, raw tailings, soil-amended tailings, and lime-amended tailings. The number of treatments was kept to a minimum in order to maximize the number of species tested.

Filter paper was used as a control. The raw or unamended tailings were passed through a 2mm sieve. The third and fourth treatments were tailings mixed with an amendment.

Table 1. Species Chosen for Germination Tests

Ref. No.	Scientific Name (Common Name)
1.	*Agropyron cristatum* (Fairway Crested Wheatgrass)
2.	*Medicago sativa* (Rambler Creeping Alfalfa)
3.	*Kochia scoparia* (Kochia)
4.	*Koeleria cristata* (Junegrass)
5.	*Festuca ovina* (Covar Sheep's Fescue)
6.	*Astragalus cicer* (Monarch Cicer Milkvetch)
7.	*Elymus giganteus* (Russian Wild Rye)
8.	*Agropyron riparium* (Streambank Wheatgrass)

Preliminary chemical characterization indicated that pH may be of most concern for revegetation, being in the range of 4.5. Agricultural grade lime (calcium carbonate) was used as an amendment to neutralize pH. Soil was also chosen, not only for its pH buffering capabilities, but also to provide an improved growth medium and source of essential nutrients. The soil used for this study was taken from the top 15cm of the Ah horizon of an uncultivated area (brown chernozem) adja-cent to and upwind of the tailings.

The two amendments were added to the raw tailings in quantities necessary to raise the pH to 6.5 over a 24 hour period. Tests indicated the following ratios (by weight): 1 part lime to 25 parts raw tailings; 10 parts soil to 25 parts raw tailings. The soil was first passed through a 2mm sieve. The dry amendments and tailings were weighed out and then blended by hand.

The tests were conducted in petri dishes, with about 20 grams of tailings or amended tailings in each dish (apart from the controls). Ten seeds were added to each of 10 dishes, for each combination of species and treatment - 3200 seeds in all. Certified #1 seed was used for *Agropyron cristatum* (#1), *Festuca ovina* (#5) and *Astragalus cicer* (#6). All other seed was Common #1, except *Kochia scoparia*, of unknown grade.

The dishes were placed in indirect sunlight with additional fluorescent light on a laboratory bench. Watering was done with demineralized water on a demand basis. The tests were conducted until the number of seeds still likely to germinate was insignificant.

Approximately 12 observations of each species were performed over the 18 day experiment. The number of seeds in each of the following four categories was recorded; non-germinated seed or dead seedling; germinated, or burst seed coat; radical longer than 1cm (positive geotrophic response); cotyledon free of the seed coat (dicots) or appearance of leaf sheath (monocots); and, appearance of the first true leaf (dicots), or emergence of the leaf from the leaf sheath (monocots).

Preliminary Observations

At the time of writing, the statistical analyses of the germination data are not yet complete. Therefore, only observational data are reported, in point form below. The maximum number of seeds for each combination of species and treatment to reach each of the four data categories is summarized in Table 2.

Table 2. Number of Seeds Reaching Each Growth Stage (n=100)

Stage 1. Germination

Treatment	Species* 1	2	3	4	5	6	7	8
control	80	79	33	21	75	30	0	98
raw tailings	87	86	19	14	55	16	0	96
soil/tailings	97	74	20	16	52	16	0	98
lime/tailings	93	78	23	25	54	18	0	95

Stage 2. Radical >1cm

Treatment	Species 1	2	3	4	5	6	7	8
control	80	77	23	21	75	27	0	98
raw tailings	87	81	19	14	54	16	0	96
soil/tailings	97	72	17	16	50	14	0	98
lime/tailings	93	76	19	25	54	15	0	95

Stage 3. Cotyledon/Leaf Sheath

Treatment	Species 1	2	3	4	5	6	7	8
control	79	67	21	21	75	25	0	97
raw tailings	86	20	4	14	54	16	0	95
soil/tailings	95	17	6	16	50	9	0	95
lime/tailings	92	24	6	24	54	7	0	88

Stage 4. First Leaf

Treatment	Species 1	2	3	4	5	6	7	8
control	79	36	0	20	74	1	0	96
raw tailings	81	1	0	13	51	6	0	91
soil/tailings	93	0	0	15	50	0	0	92
lime/tailings	85	1	0	22	22	0	0	80

*Ref. Number	Scientific Name	Common Name
1.	*Agropyron cristatum*	Fairway Crested Wheatgrass
2.	*Medicago sativa*	Rambler Creeping Alfalfa
3.	*Kochia scoparia*	Kochia
4.	*Koeleria cristata*	Junegrass
5.	*Festuca ovina*	Covar Sheep's Fescue
6.	*Astragalus cicer*	Monarch Cicer Milkvetch
7.	*Elymus giganteus*	Russian Wild Rye
8.	*Agropyron riparium*	Streambank wheatgrass

1. There is an inverse relationship between average germination time and germination rate (Figure 1).

2. Although overall growth rates appeared to be consistent within each group of dishes, some variation in germination rates occurred within the same treatment and species. This is likely due to minor differences in watering and light. The experimental design of ten separate dishes for each group of seeds appeared to minimize these sources of error.

3. To determine whether the low germination rates in species #3, 4, 6 and 7 were due to insufficient light, all eight species were germinated under a high-intensity 1000W metal halide lamp. Significant differences occurred in only two species, *Festuca ovina* (#5) and *Astragalus cicer* (#6), where rates were 50% higher.

4. For *Agropyron cristatum* (species #1), germination rates were very high for all treatments. Most germinated seeds reached the first leaf stage, although the loss rate was lower in the control than in the other treatments.

5. *Medicago sativa* (#2) showed high germination rates in all treatments. In the control, only 46% of the germinated seeds reached the first leaf stage, with significant losses in both the radical and cotyledon stages. Negligible numbers of seeds reached the first leaf stage in the raw tailings, and soil and lime amended tailings, with the majority of losses occurring before the cotyledon stage.

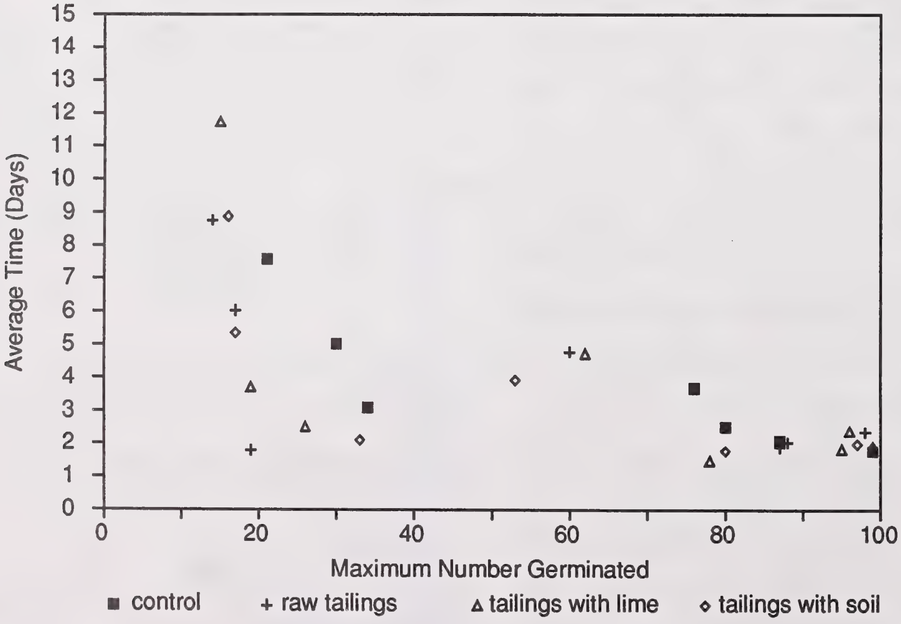

Figure 1. Germination Rate vs Average Time to Germination

6. *Kochia scoparia* (#3) had low germination rates - in the order of 30% for the control, and 20% in the three tailings treatments. None of the seeds reached the first leaf stage. The greatest losses occurred prior to the radical stage for the control, and prior to the cotyledon stage in the other treatments. This species showed the greatest susceptibility to fungi. The Kochia seed used was two years old; this may have negatively affected germination rates.

7. *Koeleria cristata* (#4) had even lower germination rates, ranging from 14% in the raw tailings to 25% in the lime-amended tailings. However, the majority of germinated seeds reached the first leaf stage in all treatments - the greatest loss was 12% in the lime-amended tailings.

8. *Festuca ovina* (#5) had a good germination rate in the control (75%), with slightly lower rates (around 55%) in the other treatments. Like *Koeleria cristata*, the majority of germinated seeds reached the first leaf stage in all treatments, with the greatest loss being 11% in the lime-amended tailings.

9. *Astragalus cicer* (#6) had low germination rates - 30% in the control and 16 to 18% in the other treatments. The number of seedlings reaching first leaf stage was negligible, aside from a small number in the raw tailings. The majority of seedlings in the control and raw tailings reached the cotyledon stage. The losses in the soil and lime-amended tailings occurred evenly before the cotyledon stage and before the first leaf.

10. *Elymus giganteus* (#7) did not germinate at all. The species was relatively unaffected by fungi. The lack of germination is likely due to seed storage conditions or species requirements for some pre-germination treatment.

11. *Agropyron riparium* (#8) had the highest germination rate in all treatments of all the species (97% on average). The majority of germinated seeds reached the first leaf stage, with the greatest losses (16%) occurring in the lime-amended tailings, and the lowest (2%) occurring in the control.

Initial Indications

Agropyron cristatum (#1), *Festuca ovina* (#5) and *Agropyron riparium* (#8) were generally successful to the first leaf stage, regardless of treatment. *Medicago sativa* (#2) showed good germination rates, but was the only species which seemed to show phytotoxicity, i.e. where growth was slower in the raw and amended tailings than in the control. *Elymus giganteus* (#7) did not germinate at all, in any of the treatments.

Kochia scoparia (#3) and *Astragalus cicer* (#6) had low germination rates, and negligible numbers reaching the first leaf stage. *Koeleria cristata* (#4) had a low germination rate, but the majority of germinated seeds reached the first leaf stage.

The chosen growth stages appear to provide an adequate basis for observation of growth. Differences between species and between treatments are apparent. Figure 2 illustrates differences in growth on Day 9 between *Agropyron cristatum*, which appears to show no sensitivity to the tailings, and *Medicago sativa*, which does. The 18 day experimental period appears to be adequate for most species to achieve germination (Figure 3).

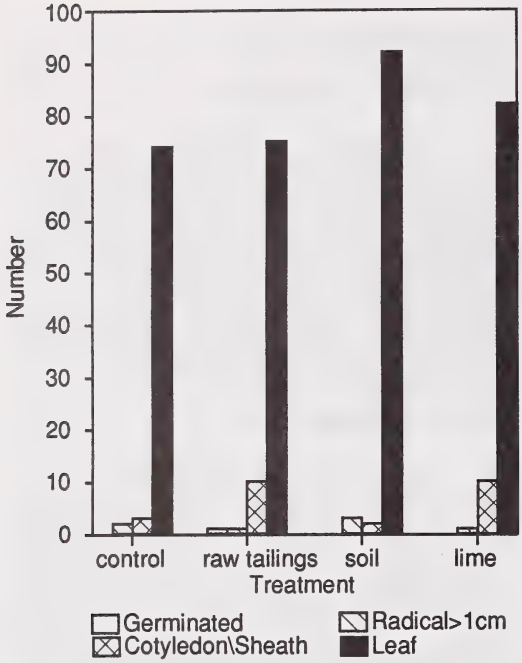

Figure 2a. *Agropyron cristatum:* Day 3

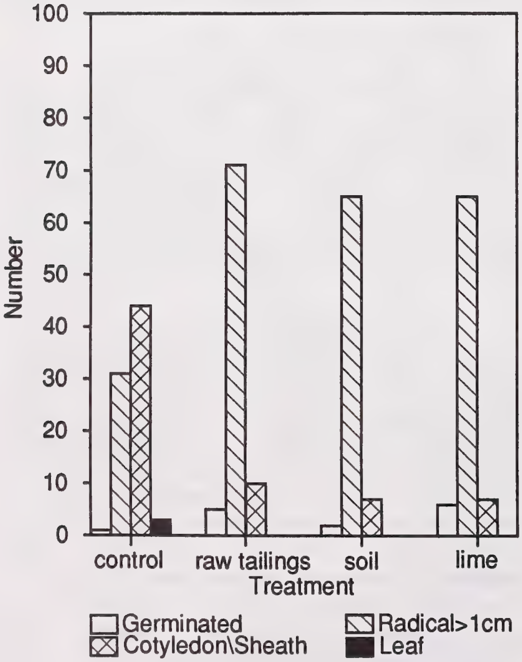

Figure 2b. *Medicago sativa:* Day 3

Seed quality is of primary importance for obtaining meaningful results in a study of this kind. The seed used should be the freshest obtainable, and have been stored under appropriate conditions.

The leaf sheath in monocots seems to appear at the same stage in growth as the cotyledons in dicots, and therefore seems a useful indicator for determining stages of growth.

Fungi are generally associated in this study with high mortality rates prior to germination or at the point of germination, although there is wide variation between species. In case there is a causal relationship between fungi and seed mortality, in future work air circulation will be used and watering kept to a minimum.

Soil appears to be a more effective amendment than lime, yielding higher number of seeds in each growth stage, except for *Koeleria cristata* (#4). Since soil could act to ameliorate phytotoxicity or be supplying nutrients which are deficient in the tailings, this will be examined furthur.

Low germination rates are not necessarily indicative that a particular species is unsuitable for reclamation work. Use of early growth data such as the first leaf stage may provide a better indication than germination alone. The establishment and growth of a species on a reclaimed site is, of course, the final criterion. In the next stages of the study, attention will be given to other means of measurement such as total biomass and seed production.

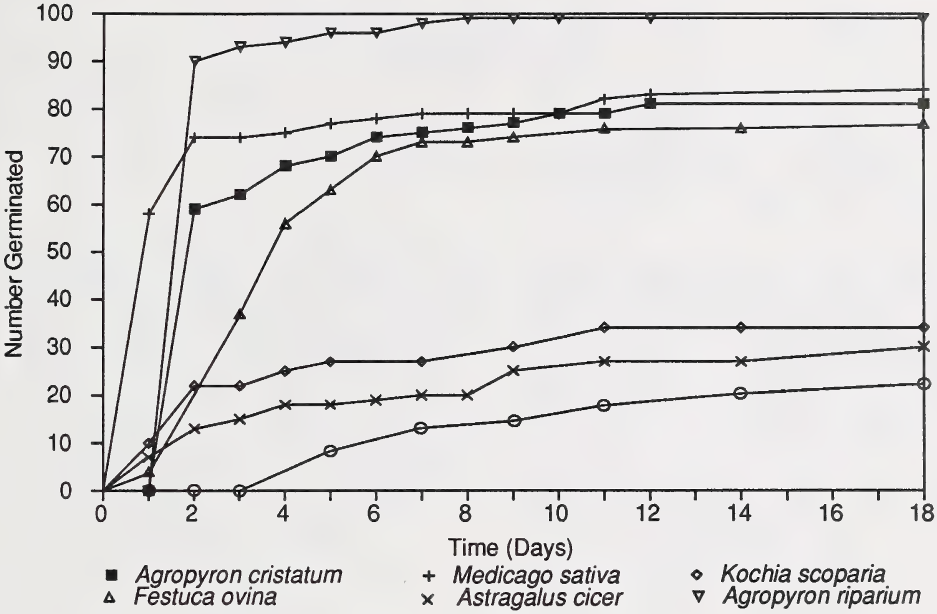

Figure 3. Germination Rate vs Time: Control

Future Work

Due to the low germination rates of half of the species used in this study, and the differences in response between different species to the tailings and amendments, the work will be repeated with several more species. These will be tested first on filter paper to select those with the best germination rates.

Once the germination and early growth test portion of this study is complete, the analytical data involving measurements of nutrient and heavy metal concentrations will be analyzed. These results will be used to select an amendment or set of amendments which allow growth of desirable species on the tailings for a minimum cost.

The next stage in the study will involve longer-term greenhouse tests. These will examine whether the selected amendment added to the raw tailings will provide adequate nutrients to establish vegetative cover, and whether heavy metal uptake varies between species, and what threat it may pose to wildlife.

Acknowledgements

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INDUSTRIAL SITE DECOMMISSIONING AND RECLAMATION[1]

by

D.N. Graveland and A.E. Osborne[2]

Abstract Monenco Consultants Limited of Calgary has been actively working on industrial site decommissioning projects for the past ten years. During that time Monenco has published a guide to the environmental aspects of industrial site decommissioning which identifies the range of activities involved in the planning and implementation of industrial site decommissioning, cleanup and reclamation. The guide outlines a step by step approach which requires the involvement of expertise from a wide range of disciplines. This paper highlights issues, concerns, and challenges facing individuals practicing soil science within the interdisciplinary framework of industrial site decommissioning projects.

Introduction

The modernization of Canadian industry, consolidation of manufacturing into larger more efficient operations, and the switch to a more service oriented society have resulted in changes in land use patterns around major industrial centres and increased the need for site cleanup and reclamation activities. Although these changes in land use are most obvious in urban centres, a shift from industrial to agricultural land use is not uncommon in rural Alberta.

When a decision is taken to decommission an industrial facility, the determination of the need for and extent of site cleanup will require the completion of a series of assessments and investigations. Waste management practices, byproduct storage methods and spills of chemicals or byproducts during plant operations may have resulted in the contamination of soils, sediments, surface waters or groundwaters on the plant site. In addition, catalysts, sludges and residues within process vessels, gutters and sumps may require special handling and disposal methods.

Waste handling and disposal can be expensive, especially if the wastes are considered hazardous. Pre-planning, proper site inventory, and development of site specific end land use cleanup guidelines, are important steps in the management and cost control process of any cleanup program.

Regulatory commitment to public health protection through legislation and implementation of supporting regulation is necessary to set industrial standards to which all real property owners can respond. In Canada, policy development is led by the Canadian

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[1] Paper presented at the 1989 Joint Conference of the Canadian Land Reclamation Association and American Society for Surface Mining and Reclamation, Calgary, Alberta, Canada, August 28-31, 1989.

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Council of Resource and Environmental Ministers (CCREM). CCREM committees are responsible for responding to public environmental concerns by overseeing the development of such things as soil cleanup criteria. Public concern for environmental issues provides a vehicle for the detection of priorities and thereby justification for public financial support for CCREM Committee(s) and provincial environmental regulatory action.

This paper focuses on the technical aspects of plant site assessments, the detection and delineation of contaminants and the development and implementation of site cleanup plans. New trends in procedure for the development of industrial site cleanup guidelines are also presented.

Environmental Concerns at Industrial Facilities

When an industrial site is decommissioned a variety of environmental concerns that may ultimately impact on the reclamation success and the acceptability of the site for future land uses must be addressed. These concerns will be a function of:

1. the product produced and type of chemical and/or manufacturing processes employed;
2. waste management facilities and procedures utilized when the plant was in operation;
3. the geologic and hydrogeologic setting of the site;
4. the age of the facility;
5. site size and location;
6. backgrounds levels of parameters of concern; and.
7. regulatory requirements.

While the precise nature and extent of environmental concerns at any given facility are highly site specific, some generalizations are possible. The following areas, facilities or contaminants are common to many industrial plants and are those most likely to represent or generate concerns at decommissioning;

1. fuel/chemical storage areas;
2. wastewater impoundments;
3. waste/by-product storage areas;
4. landfills;
5. asbestos insulation and fire proofing;
6. sludges and sediments in building gutters and sumps;
7. process equipment and services;
8. underground tanks and services;
9. PCP wood treatment facilities or wood storage yards;
10. PCB's in electrical equipment; and,
11. sewage lagoons.

Guide to Decommissioning Industrial Sites

Addressing site specific environmental concerns requires a flexible approach. In response to this need Monenco prepared a guide to assist industry and government in the decommissioning process. Development of the guide was sponsored by Environment Canada, the Petroleum Association for the Conservation of the Canadian Environment, Canadian Chemical Producer's Association, and the Canadian Petroleum Association.

The Guide to the Environmental Aspects of Decommissioning Industrial Sites (Monenco Consultants Limited 1985) identified a stepwise approach to decommissioning industrial sites. The main elements of this approach are shown in Figure 1. By following the sequence of activities in a step-by-step manner, the assessment of plant site conditions and the design and implementation of site cleanup will be all-encompassing and cost-effective to permit redevelopment of the site. The approach is flexible and responsive to specific site conditions; the level of effort required for each activity is dictated by site conditions and previous waste management practices.

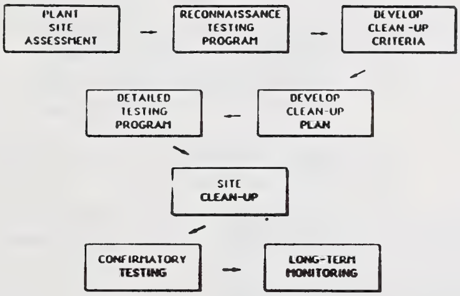

Figure 1 - Main elements of step-wise approach

Plant Site Assessment

The objectives of conducting a plant site assessment are to identify potential environmental concerns associated with plant operations, and accordingly, to provide the basis for the design of sampling and analytical programs. The plant site assessment includes a review of available background, process and waste management information. In addition to the examination of old aerial photographs and construction drawings and files, the site assessment should consider site soils and groundwater information; processing details; composition of solvents, inhibitors, water treatment and other chemicals; available information on solvent degradation products; mercury use; records of spills and leaks; operational details of the plant landfill; disposal practices for sludges and spent catalysts; and operational details of wastewater treatment systems.

Much of the background information can be assembled from discussions with long-term employees of the plant. A thorough assessment should also include detailed site inspections and examinations of key areas.

Reconnaissance Testing Program

Environmental investigations which involve extensive sampling and analysis are more effective if undertaken in phases. The first phase is a reconnaissance program designed to provide indications of contamination and to provide the basis for detailed investigations in certain areas. In some cases, the reconnaissance program may show that subsequent detailed investigations are not required.

The main objectives of a reconnaissance testing program are to:

1. identify the types of contaminants, range of contaminant concentrations and general locations of contaminant concerns; and

2. clarify the geologic and hydrogeologic conditions of the site and surrounding area.

The design of the reconnaissance program would include a consideration of the possible types and locations of contaminant concerns at the site and geologic and hydrogeologic factors. In this way, procedures can be established for the collection of representative samples and for the analysis of chemical parameters of concern.

Field Work. Reconnaissance-level sampling at a typical industrial site may include:

1. a survey of the site using surface geophysics to identify near-surface soil disturbances, shallow groundwater concerns and the location of buried waste pits;

2. sampling of soils from boreholes or test pits located in areas of

concern. Samples would normally be collected at the surface and at various intervals to a depth below buried services;

3. the establishment of soil sampling sites on a widely spaced grid or at sites located radially outward from a contaminated source to provide an initial estimate of the possible extent of contamination;

4. sampling sediments in drainage ditches which collect runoff from process areas, landfills and product/waste storage areas;

5. sampling sediments and sludges from oily water separators, process wastewater ponds and surface water runoff ponds. Grab samples may be sufficient for a reconnaissance characterization of these sediments and sludges; but, if large sludge accumulations exist, coring devices may be required to collect representative samples;

6. establishing the geologic and hydrogeologic setting of the plant by drilling boreholes at selected locations, collecting samples of soils, overburden and bedrock and installing piezometers to determine rates and direction of groundwater flow;

7. installation, testing and sampling of piezometers in areas of concern. These may include a series of piezometers installed at various depths in the vicinity of wastewater ponds, process facilities, hydrocarbon storage facilities, chemical handling areas, previous spill locations and landfills;

8. excavation of test pits or drilling of boreholes in the landfill to determine the nature and extent of buried wastes and to undertake selected sampling;

9. location of background sampling sites at off-site locations away from the influence of the plant and sampling of soils and groundwater to determine background chemical composition; and,

10. completion of other miscellaneous sampling to assist in the evaluation of conditions at the site. These may include:

    - in-building residue samples from gutters, sumps and process vessels;
    - samples from the laboratory sump and areas where mercury may have been handled;
    - transformer fluid samples to determine the presence of polychlorinated biphenyls (PCBs); and,
    - process or water treatment chemicals which may not be completely characterized.

Analytical Program. The quality of analytical results is one of the most important aspects of environmental investigations. Analytical quality control is equally important in decommissioning studies, particularly in relation to the detection of trace quantities of various contaminants and in the quantification of waste materials which may have to be handled, treated and disposed of by costly methods. Therefore laboratories selected for the analysis of samples should be experienced in the analysis of environmental samples, possess instrumentation to accurately detect and confirm contaminant concentrations and have internal quality control programs to ensure the precision and reproductibility of analytical determinations (Monenco Consultants Limited 1987).

For a reconnaissance testing program, the analytical parameters should include all potential chemical contaminants. It is effective to analyze some of the samples in phases, for example, one or two samples from a borehole could be analyzed in the initial phase and further sample analyses would be determined by the initial results. The use of indicator parameters and multi-element scans has proven effective in reconnaissance investigations, followed by more detailed analyses as required.

The initial analytical results may dictate further analyses to confirm any contaminant indications. These may include:

1. analysis of certain elements by atomic absorption; and,

2. identification of the organic composition of certain samples by gas chromatography/mass spectrometry (GC/MS).

Development of Cleanup Criteria

The reconnaissance testing program will provide the chemical composition of soils, sediments and groundwaters on the site. These can be compared to the chemical composition of background samples and it may be found that certain chemical concentrations are in excess of background levels. However, the significance of elevated concentrations is directly related to the magnitude of measured levels, the proposed future use of the site and the plant site setting. To determine the maximum contaminant concentrations that may safely remain in soils and groundwaters without causing adverse health and environmental effects, cleanup criteria are required.

Cleanup criteria are benchmarks which identify the significance of contamination on the site and are subsequently the 'numbers' which define the extent of site cleanup. Criteria are directly related to the anticipated future use of the site as well as geologic, hydrogeologic and other site-specific factors. The criteria must be developed on a sound scientific basis to protect future users of the site.

At present, there is limited precedence for the development of cleanup criteria, particularly related to potential health effects of contaminants in soils. Dependent on future land use, considerations may include:

1. soil/crop relationships with respect to crop phytotoxicology and to animal grazing or the production of feed or food crops;

2. potential effects of ingestion, inhalation or dermal exposure of wind blown dusts or vapours;

3. potential effects of inadvertent ingestion of contaminated soils (such as may occur with children at play);

4. biodegradability of organics in soils or groundwaters; and

5. potential effects of contaminants on construction materials.

When the cleanup criteria are finalized, the process of determining cleanup needs can proceed.

Few jurisdictions have established acceptable soil concentrations or cleanup guidelines. To address various pressing issues concerning the decommissioning of industrial sites in Canada, a national Decommissioning Steering Committee was formed that includes representatives from the Provinces of Alberta, Ontario, and Quebec, the Canadian Petroleum Association, the Canadian Chemical Producers Association, and the Petroleum Association for Conservation of the Canadian Environment. The Committee is chaired by Environment Canada.

In late 1986, the Decommissioning Steering Committee decided to act upon one of its highest priorities and initiate the development of a method for setting site-specific cleanup guidelines. Early in 1987, a contract was awarded to a consortium headed by

Monenco Consultants Limited to review the approaches of other agencies to setting guidelines; recommend an approach for Canadian agencies; and develop a method that demonstrates the recommended approach. The total project was funded jointly by the members of the Decommissioning Steering Committee.

The objective of the project was to produce a computer model that can be used to derive cleanup guidelines for industrial sites where redevelopment is being considered or planned. The result is the "demonstration" version of the Aid for Evaluating the Redevelopment of Industrial Sites (AERIS) model. The current form of AERIS is referred to as the "demonstration" version because it contains sufficient information for only seven contaminants (four organic compounds and three metals), four types of future land use, characteristics of two types of receptors, the meteorology of six Canadian cities, the characteristics of nine soil types, and the characteristics of 14 types of geological formations.

When the system becomes fully operational, AERIS will be an attractive aid for a broad spectrum of potential users as follows:

1. AERIS could be used by any regulatory agency asked to comment on the "acceptability" of a contaminated site for a proposed use, determine whether cleanup efforts are necessary, or identify cleanup objectives;
2. AERIS could be used by any current owner of a site interested in knowing whether remediation may be necessary and, if so, to what extent. For contaminants that have not been addressed by regulators, AERIS could be used to give the first approximation of the cleanup guideline that eventually may be established;
3. AERIS could be used by a prospective buyer of a contaminated site to determine if current site conditions are suitable for various potential uses or to determine the level of risk of liability associated with site;
4. AERIS could be used by a consultant assisting any of the above parties;
5. AERIS could be used by educators to demonstrate to students the interrelationships between environment and dose and as a means for incorporating risk assessment into the decision-making process; and,
6. AERIS could be used by any interested party to investigate the sensitivity of the final results to specific parameters and thus help the scientific community to identify those factors and conditions that have the greatest influence in establishing soil guidelines. Where resources are limited, attention should first be paid to improving confidence in the key factors.

Detailed Testing Program

The reconnaissance testing program provides data on the types of contaminants, ranges in concentration and generalized locations of contamination. If contamination concerns are identified on-site, a further investigation is required to provide details for cleanup and reclamation of the site. The detailed investigation will focus on those concerns that are judged to be significant in terms of the cleanup criteria, and will provide additional reclamation-related information required to assist in the evaluation of cleanup and reclamation alternatives.

A detailed testing program may include:

1. establishment of the boundaries of areas contaminated with chemicals or compounds at levels greater than cleanup criteria;
2. clarification of hydrogeologic conditions and examination of temporal groundwater quality concerns;
3. determination of the form and mobility of chemical contaminants through detailed chemical analyses and leaching tests; and,
4. compilation of site-specific factors such as moisture/density relationships, buffering capacity, ion exchange capacity, etc., which will be necessary to develop cleanup and reclamation measures.

Preparation of Cleanup Plan

The completion of a detailed testing program at the site and finalization of cleanup criteria will permit the development of a cleanup plan. This plan will thoroughly define cleanup actions, measures for worker health and safety and treatment and disposal of wastes. The evaluation of cleanup options may necessitate a change in the desired future use of the site if cleanup to established criteria cannot be achieved due to technical or economic reasons.

The cleanup plan, when completed, would normally be integrated with other decommissioning activities (i.e. removal of buildings, equipment, etc.) and would contain detailed descriptions of all cleanup, reclamation, containment and monitoring plans.

Site Cleanup

When the cleanup plan is finalized, cleanup of the site can commence. Depending on site conditions, it may be undertaken over several years, or may be a relatively simple and straightforward program involving the removal of byproducts and processing components and disposal of sludges. While cleanup activities vary from site-to-site, important factors which must be considered in the implementation of a cleanup plan are the collection and treatment of wastewaters during the cleanup program, provisions for worker safety and health and the sequence of cleanup activities.

A typical sequence of cleanup actions is summarized as follows:

1. removal of byproducts, chemicals and catalysts;
2. removal of in-building sludges and residues;
3. removal of process equipment;
4. cleaning of building interiors;
5. dismantling of buildings;
6. removal or sealing of buried services;
7. installation of containment facilities;
8. excavation of contaminated soils and sediments;
9. implementation of in-place reclamation measures; and
10. installation of long-term monitoring facilities.

Confirmatory Testing

When site cleanup is completed, or when phases of a multi-phase cleanup program are completed, confirmatory testing is required to ensure that the task of removing contaminants from the plant site or reclaiming contaminated soils has been effective.

With respect to areas of excavation, the confirmatory testing program would involve sampling of soils within and nearby excavated areas and analysis of samples with respect to cleanup criteria. Usually an independent contractor (i.e. one who has not previously been involved in site investigations) would conduct the confirmatory testing program.

Other confirmatory testing would likely be carried out in conjunction with long-term monitoring of the site.

Long-Term Monitoring

Requirements for long-term monitoring of site conditions will vary from site-to-site, and will provide assurances that cleanup and reclamation programs have been effective. Monitoring may include groundwater, surface water runoff, biodegradation rates and metal uptake in crops. The monitoring program may continue for several years and may be gradually phased out when sufficient monitoring data demonstrate the integrity of the site.

Cost Implications

The costs of mitigating environmental concerns at a decommissioned industrial facility will depend heavily on the nature of materials and wastes produced and the extent to which they have been properly managed during the facility's lifetime. Costs can easily range into the millions of dollars for facilities operated using the less than rigorous waste management practices commonly applied in the past. In some instances, current practices still do not provide for adequate management of environmental risks and may eventually result in high decommissioning costs.

Overview

Ideally, site decommissioning, cleanup and reclamation planning begins at site selection phase of project development. It is at this time that critical site characteristics such as soils, groundwater, geology and the interaction between site factors should be evaluated as to their sensitivity to the types of contaminants likely to be found on site after development is complete. Data from this early site evaluation procedure can then be integrated into the development program and thereby minimize the need for expensive site decommissioning and cleanup activities later on.

At older plant sites the damage has often already been done. Decommissioning and reclamation specialists must implement a number of studies to find out what contaminants have been released, what risk to human, animal and environmental health these contaminants pose on site and what potential hazards off-site soil contaminant migration might be.

Research is required into the development of site-specific cleanup criteria, biodegradation properties of organic compounds, uptake of heavy metals by plants, rate of contaminant migration through soils, soil solidification and disposal methods, and leachate treatment systems. Based on knowledge of these factors environmentally appropriate cleanup procedures will ultimately be more cost-effective and ultimately pose less risk to future land use.

Summary

Environmental concerns which may require cleanup or reclamation actions at retired industrial sites are directly related to site geologic and hydrogeologic conditions and previous waste management practices. By completing the sequence of assessments, investigations and cleanup evaluations identified herein, the cleanup of an industrial site will be cost-effective and successful. The site can then be safely re-developed for other uses.

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A TECHNICAL AND ECONOMIC EVALUATION OF SULPHUR BASEPAD RECOVERY AND RECLAMATION[1]

by

S.L. England and S.A. Leggett[2]

Abstract. Sulphur block basepad recovery has been ongoing in Alberta since the early 1980's. A variety of techniques that rely on various degrees of off-site disposal have been used extensively. Recovery techniques range from extensive use of landfills for disposal of sulphur contaminated material to attempts to neutralize and reclaim the material on site. The problems and costs of site reclamation vary depending on site location, conditions, and basepad recovery techniques. While the location and condition of the sites are fixed variables, choices of recovery techniques can influence the success of reclamation programs. This paper reviews the techniques used for recovery and reclamation to date, investigates the problems and costs associated with each and provides case history information from work undertaken by Mobil Oil Canada.

Introduction

Hydrocarbons extracted from a reservoir that has a significant amount of hydrogen sulphide are referred to as sour oil and sour gas. Alberta produces 95% of Canada's elemental sulphur by converting the hydrogen sulphide present in sour oil and gas to elemental sulphur through a controlled oxidative method called the Claus Process (Hyne 1977).

The majority of sour gas plants built in the 1950's to early 1970's stored elemental sulphur by pouring molten sulphur into a large block. The block was poured on top of a basepad, that was also formed from molten sulphur. Many of these basepads were poured directly onto soil, with minimal ground preparation.

There are approximately 105 basepads at 34 locations in western Canada (Hyne and Schwalm 1983). The total area of the basepads is estimated to be 100 hectares. Since 1980 few, if any, new basepads have been established. Therefore, most basepads and associated blocks have been in place for at least ten years. As a result of increased sulphur sales and declining hydrocarbon reserves in older sour oil and gas fields, sulphur blocks are being depleted.

Once a sulphur block has been recovered, the basepad remains. Approximately 10% of the total sulphur inventory in Alberta is comprised of basepad material. The removal of the basepad can be an expensive aspect of sulphur block clean-up depending on the thickness of the sulphur:soil interface and the degree of mixing that has taken place. The extent of basepad clean-up operations will dictate how much sulphur will remain as a contaminant in the underlying soil.

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[1] Paper presented at the conference Reclamation, A Global Perspective, held in Calgary, Alberta, Canada, August 27-31, 1989.

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Once basepad clean-up is completed and the sulphur-contaminated soils are exposed, sulphur oxidation and resulting soil acidification will occur if the soil is left untreated. Former basepads must be neutralized and plant owners must satisfy regulatory authorities that the sites will not pose environmental hazards. Alberta Environment has implemented a program whereby all former industrial sites must be reclaimed. The site must be restored sufficiently to safely accommodate future land use activities. In addition contaminants may not remain in quantities that could migrate offsite, affect the quality of adjacent land, or pose an environmental threat. Clean-up requirements are ensured under a number of pieces of legislation including the Hazardous Chemicals Act, the Land Use Act, the Planning Act and the Clean Water Act.

Overview of Recovery and Disposal Options

The objectives of a basepad clean-up are two-fold. One is to remove as much pure sulphur as possible so that the product can be marketed. The second objective is to minimize the degree of soil:sulphur mixing that generates contaminated soil that must either be disposed of or reclaimed. A review of basepad recovery systems is presented in Schwalm et al (1985).

Two main approaches have been used in the clean-up process. The first approach which has been used in the majority of cases is to remelt and recover pure sulphur from as much of the basepad as possible. This procedure requires that extreme care be exercised by the operator to avoid excessive mixing of the soil:sulphur interface. To attain marketing specifications, relatively pure sulphur is blended in the melter with contaminated materials from the soil: sulphur interface.

The end result of this process is sulphur-crete; a concrete-like material. The sulphur-crete and contaminated soil which generally contains at least 30% sulphur has traditionally been disposed of in a landfill.

Using the remelt procedure, 5,000 - 10,000 tonnes of material may require disposal. Depending on the volume of wastes and the proximity of the site to a landfill that will accept sulphur-contaminated wastes, disposal costs would average about $35/tonne for a total cost in the range of $150,000 to $350,000.

Depending on the initial site preparation and the amount of contaminated material removed, final soil sulphur concentrations generally range from about 5-20% sulphur prior to initiating reclamation.

A second approach has recently been commercially developed by Husky Oil Operations Ltd. that employs a cold mining flotation process. This system is capable of removing higher amounts of sulphur from contaminated soil than most remelt operations can achieve (D. White pers. comm.).

The facility is designed to process material that contains 80% sulphur and 20% contaminants (including soil). Highly contaminated materials such as those removed from the soil:sulphur interface are blended with pure sulphur to provide a high enough overall sulphur concentration to achieve efficient recovery. The use of this process, therefore, requires preplanning as the entire basepad must be processed rather than just the sulphur-contaminated soil.

The tailings from the process are estimated to contain sulphur concentrations of approximately 8-10%. This material is considered suitable for landfarming. Therefore, this method allows recovery of maximum levels of sulphur and does not rely heavily on landfilling of wastes.

Processing costs are $50/tonne plus trucking charges. Assuming an average trucking rate of $15/tonne and an average weight of 30,275 tonnes of material for processing, costs would be approximately $1.97 million. This would correspond to sending a basepad of approximately 30 cm thickness and an associated 15 cm depth of contaminated soil over a 3.2 ha area.

Assuming a bulk density of 2.0 g/cm^3 there would be approximately 21,475 tonnes of sulphur. Assuming that one acre of soil taken to a depth of 15 cm weighs 1100 tonnes, this combination of basepad and soil would be approximately 70%, by weight, sulphur and 30% contaminant.

Revenue is generated from the sale of the pure sulphur that is recovered. Assuming a recovery rate of 98% and a selling price of approximately $80/tonne for sulphur, approximately $1.68 million revenue would be generated. Actual disposal costs would therefore be approximately $284,000.

A cost comparison can be estimated if a remelt operation was used for recovery of a similar basepad, assuming a recovery rate of 80% and a processing fee of $39/tonne. Processing costs would be $1.18 million and the revenue generated from the sale of pure sulphur would be $1.37 million. Subtracting disposal costs of approximately $250,000 would mean that the cost of recovering the basepad would be approximately $55,000.

An advantage of using the remelting process is that the plant owner keeps a greater proportion of the revenue generated from the sulphur sales. A disadvantage is that disposal of large amounts of sulphur in the form of sulphur-crete and sulphur-contaminated soil to a landfill is required.

A disadvantage of the cold mining process is the greater loss of income to the plant owners from the sale of pure sulphur. The major advantage of the second method is the reduced percentage of sulphur in the tailings and the reduced volume of tailings requiring disposal.

Overview of the Reclamation Process

When basepad sites were levelled prior to construction the topsoil was usually stripped and molten sulphur poured directly onto the subsoil. Over the years the stripped topsoil was often used for other purposes, leaving a subsoil surface to be reclaimed when basepad recovery is complete.

The focus of a reclamation program on former basepad sites becomes two-fold then, firstly neutralizing the potential acidity and secondly, restoring a subsoil to a quality capable of sustaining vegetative cover.

The first objective is to neutralize acidity generated by the biological and chemical oxidation of elemental sulphur into sulphuric acid. The degree to which the soil will become acidified will depend on the amount of elemental sulphur and calcium carbonate present, the extent and rate of sulphur oxidation, and the specific nature of the soil.

The second objective is to improve the organic carbon content and structure of the subsoil so that it can support plant growth. This can be accomplished by adding organic matter in the form of animal manure and/or straw. Additionally, the sites can be seeded with plants that can be ploughed down as green manure. Establishing plant growth also helps to improve soil tilth through the penetration of roots into the soil, thus improving soil aeration and moisture penetration conditions.

It is well documented that acidified soils can be reclaimed by amending the soil with calcium carbonate. There are several methods available to determine the amount of limestone required to neutralize an acidic soil.

The principal method used in Alberta is based on accounting for the total acidity generated if all the sulphur present in the soil was oxidized. On the basis of molecular weight and stoichiometry, calcium carbonate is required in a ratio of three parts for every part of total sulphur detected in the soil. Therefore a soil that contained 20% sulphur, by weight would require a calcium carbonate application of 60%, by weight, to the soil.

A fundamental factor influencing the extent of basepad clean-up and future reclamation success is the amount of sulphur that can be left on-site. Because of the large amounts of calcium carbonate required to neutralize all of the acidity that could be generated from the oxidation process and the varied sulphur particle sizes left in the soil, there has been a tendency to remove as much sulphur as possible from the basepads.

There is conflicting data about the amount of sulphur that can remain in the soil while still achieving effective reclamation. Results from one greenhouse experiment indicated that reclamation of soils containing more that 4% sulphur was difficult if limestone was added in a 3:1 ratio (Leggett and Parkinson 1988). Roberts and Komadowski (1988) concluded that lack of reclamation success noted from the first year of their field study was due to the physical presence of the limestone in the soil.

Results from two other studies have indicated that soils containing as much as 10% sulphur (Nyborg 1982) and 11% sulphur (D.McCoy pers. comm.) can be limed in a 3:1 ratio and still be reclaimed. At present, there is a general consensus that reclamation of soils containing upwards of 20% sulphur would require both intensive effort and represent a long term project.

From the reclamation programs that have been undertaken to date, it is apparent that reclaiming a site that contains an average sulphur concentration of less that 5% will take at least three years and more likely five to seven years. Therefore operators are recognizing the merits of initiating liming programs immediately following basepad recovery. Prompt reclamation while the plant is still generating revenue allows the plant owners to spread the costs over a number of years prior to decommissioning.

An example of a unique approach to reclamation used at one plant site in Alberta was to leave the sulphur-contaminated soil on site once the remelting operation was completed. It was estimated that the soil contained approximately 25-30% sulphur (R. Cursons pers. comm.). Limestone was applied in a 3:1 ratio and incorporated into the soil. A 15-30 cm cover of topsoil was then spread over the entire site and the area was seeded.

To date, growth has been established over much of the site. The advantage of this approach was that the sulphur-contaminated material has been retained on-site reducing the costly step of removal to landfill. The disadvantage of this approach is that it will be difficult to place additional limestone, if required, within the zone generating the acidity.

Mobil Case Histories

Mobil Oil Canada is in the process of reclaiming former sulphur basepad sites at three facilities; Lone Pine Creek, Wimborne, and Harmattan. In all three cases, basepad recovery was carried out using an on-site remelter.

Remelting operations were initiated at the Lone Pine Creek facility in 1985, at Wimborne in 1986, and at Harmattan in 1988. The amount of material requiring disposal, the disposal costs and the average soil sulphur concentrations for each basepad once clean-up was completed are presented in Table 1.

Reclamation activities were initiated in 1987 at both Lone Pine Creek and Wimborne facilities and in 1988 at the Harmattan facility. Table 2 provides a summary of the amendments that were applied and the reclamation costs. In all cases, reclamation programs were developed based on results of soil sampling programs carried out at each site.

Table 3 provides a summary of selected soil chemical parameters measured at fixed locations at all three sites. The increase in soil pH between 1987 and 1988 at both Lone Pine Creek and Wimborne facilities was due to liming programs. The drop in soil pH in 1989 at Lone Pine Creek indicates that re-acidification had occurred.

In September 1988, the average soil pH of nine bare spots was 3.9. Powdered limestone was applied to these areas in November 1988 at rates of 44-80 tonnes/ha, depending on results from lime requirement tests. Despite this limestone application, the average pH of the same nine bare spots in May 1989 had dropped to 3.5.

Six plots, each measuring 18.3m x 44.2m, were established in 1987 on a portion of the Lone Pine Creek site to assess procedures, materials and equipment used in the reclamation program for applicability at other Mobil basepad sites. The use of two types of limestone, powdered and pelletized, was evaluated as was the merit of adding partially decomposed straw to improve soil tilth. Details of this field experiment are outlined in Leggett et al (1988).

Based on soil chemical analyses and above-ground biomass measurements, it was concluded that for flat, relatively dry sites with good access for large vehicles, powdered limestone provided effective neutralization that was four times less expensive than pelletized limestone. The combination of powdered limestone and straw were the most effective, cost efficient amendments for

Table 1 Amount of Sulphur-contaminated Material requiring Disposal, Associated Costs and Levels of Sulphur remaining in soil at three Mobil Oil Canada facilities.

Site	Amount of Material Requiring Disposal (tonnes)	Disposal Costs ($)	Average Levels of Total Sulphur Remaining in Soil
Lone Pine Creek	7,750	150,000	2%
Wimborne	12,260	325,000	7%
Harmattan	13,100	400,000	2%

Table 2 Reclamation Steps Undertaken at Former Sulphur Basepad Sites of three Mobil Oil Canada facilities.

Year	Area(ha)	Amount of Limestone Applied (tonnes)	Amount and Type of Organic Matter Applied	Type of Seed Used	Annual Cost($)	Annual Cost/ha ($)
Lone Pine Creek						
1987	3.4	363	----	Barley & yellow sweet clover	23,690	6,967
1988	3.4	103	8 round bales of yellow sweet clover	Barley & yellow sweet clover	18,000	5,294
Wimborne						
1987	3.2	437	----	Fall rye & yellow sweet clover	15,000	4,687
1988	3.2	68	330 tonnes of manure and straw	----	11,000	3,448
Harmattan						
1988	3.4	145	----	----	10,625	3,125

Table 3 Summary of Selected Soil Chemical Parameters at three Mobil Oil Canada former sulphur basepad sites. Data are expressed as mean values ± standard deviations.

				Electrical Conductivity (dS/m)			Total Sulphur (%)		
		pH							
Site	1987	1988	1989	1987	1988	1989	1987	1988	1989
Lone Pine Creek (n=9)	4.5±2.1	5.9±1.8	5.3±1.4	7.3±3.3	7.7±7.7	7.1±2.8	0.5±0.5	1.7±1.6	N/A
Wimborne North Pad (n=23)	3.9±1.9	5.6±1.6	N/A	13.5±7.2	7.8±2.5	N/A	6.5±9.2	5.1±6.9	N/A
Wimborne South Pad (n=15)	5.7±1.8	6.6±1.2	N/A	10.2±3.7	7.6±1.6	N/A	7.8±4.7	4.8±4.1	N/A
Harmattan N.E. Pad (n=4)	N/A	7.7±0.3	N/A	N/A	5.8±0.7	N/A	N/A	2.5±1.2	N/A
Harmattan N.W. Pad (n=3)	N/A	7.7±0.5	N/A	N/A	5.8±0.8	N/A	N/A	1.4±1.5	N/A
Harmattan S.W. Pad (n=3)	N/A	7.3±0.3	N/A	N/A	5.7±0.3	N/A	N/A	1.5±1.5	N/A

* N/A not available.

sites similar to Lone Pine Creek. The combination of straw and powdered limestone was approximately 2.5 times less expensive than the use of pelletized limestone alone. Equipment used to apply both the limestone and straw were effective, but numerous passes were required to add the desired quantity of both powdered and pelletized limestone.

Good growth was achieved at Lone Pine Creek in 1987, although there were some bare spots that appeared again in 1988. Sampling the bare spots in 1988 and 1989 revealed that the soil was both acidic and contained high levels of soluble salts. The bare spots were re-limed in 1988 and again in 1989 prior to seeding the site.

The 1989 seed mixture selected for all three basepad sites included plants that have a tolerance for either high salt levels or low soil pH values so as to maximize germination and growth potential. Six row barley was seeded in one direction. A forage mixture composed of alsike clover, alfalfa, tall wheatgrass and brome grass was then seeded in a diagonal direction. Timothy grass was substituted for brome grass at Harmattan.

Fall rye and yellow sweet clover were seeded in the fall of 1987 at Wimborne. Seed germination and plant growth were poor, but it is thought that these results were partly due to seeding methods and the weather. The site was too wet in 1988 to work on it during the summer. The site was re-limed in the fall of 1988, based on results from the 1988 spring soil sampling program. Manure and straw were also applied in the fall of 1988. This site was seeded in June, 1989.

Reclamation work was initiated late in the fall of 1988 at Harmattan with the application of powdered calcium carbonate. The site was then cultivated, rock-picked and seeded in June of 1989.

Preliminary results indicate that barley growth will be quite good at all three sites. None of the forage mixture had germinated at the time of preparing this paper. Bare spots are still appearing at Lone Pine Creek site which is not a surprise given the high electrical conductivity values (15-25 dS/m) recorded on some of the bare spots.

A primary objective for 1989 was to seed the sites as early as possible so that it would be feasible to re-seed the bare spots in mid-summer following further reclamation treatments. Seeding these sites provides the opportunity to use growth as an indicator of areas where further work is required. Soil sampling of the individual bare spots allows the rehabilitation programs to be specifically tailored to the problem areas.

The approach taken by Mobil has been to initially apply limestone in a 3:1 ratio based on the average sulphur level over the entire basepad. Areas known to be more highly contaminated receive additional limestone. The basepads are then seeded and growth is monitored. Once the bare spots become evident, additional soil sampling is carried out. Amendments are applied to the bare spots as necessary and the areas are re-seeded.

A number of observations have been noted as a result of the work carried out on these three basepads. The first of these is that the sulphur levels across sites are highly variable. Although the average levels for each site are quite low, the range of values is very wide. The average sulphur value at Wimborne is 7% while the range is from 0.5-29%. Without sampling on a very small scale grid, it is difficult to accurately determine sulphur levels throughout each basepad.

The second observation is that some site preparation work is generally required as part of the reclamation program. This can include rock-picking and some landscaping in order to improve site drainage. It is important that acidic materials not be buried during landscaping. It is most efficient to leave the sulphur-contaminated soil on the surface where limestone can be easily mixed with it. This allows the opportunity to neutralize areas that re-acidify over the years.

The next observation is that the areas that are re-acidifying and not supporting plant growth at Lone Pine Creek exist where sulphur-contaminated piles of material, remelt pits or equipment were located during the basepad recovery operation.

The final observation is that the methods used for seeding are crucial to the success of the program. Attempts to broadcast the seed have not been highly successful at both Lone Pine Creek and Wimborne. All sites are now seeded with a seed drill. Because of the relatively small size of the sites and the even smaller size of the bare spots, farm equipment that is eight feet wide is being used. This should also allow cultivation and seeding of the bare spots without disturbing the rest of the basepad areas that are supporting growth.

Conclusions

Sulphur blocks and associated basepads will likely no longer exist in the near future as producers have chosen alternative methods for sulphur storage. Technologies and methodologies required to recover basepads and reclaim the underlying soil will only be utilized for the next ten years. Despite this short term and finite requirement, proper clean-up and reclamation programs are essential to preventing future environmental problems that could result from poor practices now.

Each basepad project must be individually evaluated when chosing recovery options. Although the cold mining flotation process is capable of removing higher amounts of sulphur from contaminated materials than most remelt operations can achieve, tailings are produced which require further treatment and/or disposal. Depending on the final concentration of sulphur in the tailings, some disposal to a landfill may be required. As the entire basepad must be sent to the facility in order for recovery to be economic, large volumes of material must be trucked.

Based on the fictitious examples outlined in this paper, it is more costly to send material to the Husky Oil facility than to remelt the basepad on-site. However, the remelting operation generates waste that contains relatively high levels of sulphur. Landfilling of this waste could create a long-term liability for the plant owners if acidic materials leached from the waste.

Remelting operations would be more environmentally acceptable and economically attractive if the sulphur levels in the tailings could be reduced. According to Schwalm et al (1985), this may be feasible through the use of a pre-conditioning process that would improve the separation of fine particles from the sulphur. Hopefully such improvements in technology can be brought on-stream quickly.

Reclamation of former basepad sites containing low amounts of sulphur (less than 5%) should be fairly straightforward. Because of the variability of sulphur levels in the soil, repeated liming and seeding operations will likely be required. The major issues in reclaiming these types of basepad sites are the logistics of accomplishing the required work and ensuring that the site is monitored and actively worked until successful reclamation is achieved.

At present, there are a couple of different approaches proposed for reclaiming soils that have in excess of 5% sulphur. Although it is not clear how much sulphur can be left in a soil and limed in a 3:1 ratio, it is understood that reclamation of soil heavily contaminated with sulphur requires a long-term commitment.

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THE REVEGETATION OF LANDFILL SLOPES[1]

by

Tom Hilditch and Joyce Gould[2]

Abstract. Erosion on landfill slopes not only results in the loss of soil, but also in potential damage to the surface soil cap covering the refuse. That damage can lead to several problems: (1) increased infiltration of rain, accelerating the production of leachate; (2) increased mobility of landfill gases and leachate; (3) exposure of refuse that attracts nuisance animals (eg. gulls, ravens); (4) reduced aesthetics; and, (5) increased costs of repair works. In a three year research study completed for the Ontario Ministry of the Environment (OMOE), all of these problems were encountered. That research program included work in three stages: (1) an overview of landfill erosion in the province; (2) identification of the best revegetation techniques; and, (3) establishment of demonstration plots. This paper will concentrate on a presentation of the final product of the three year study, a revegetation manual. The need for such a manual was reinforced during discussions with both landfill owners and operators, and regulators throughout the province. The existing techniques for revegetating closed landfills differed from area to area. There was no attempt to provide consistent direction or application of tillage, soil remediation, seeding or maintenance techniques. This was the case despite erosion problems being observed on 88% of landfills field checked. Interestingly, there were no revegetation efforts on two thirds of the sites reported on by OMOE officials. On the remaining one third, there were very few reports of anything other than the application of hydroseeding (without tillage, soil testing or followup maintenance). This paper presents the results of a Revegetation Manual produced in the final year of this study. It is intended to provide an easily comprehended and applied reference for anyone involved in the creation and maintenance of vegetation cover on landfills. The outline of the paper follows the manual's table of contents fairly closely in an effort to demonstrate the importance of the structure and composition of such a manual to the comprehension of the material by the user.

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RECLAMATION OF AN INDUSTRIAL SEWAGE LAGOON[1]

by

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Abstract. The Land Reclamation Division, Alberta Environment, was asked to reclaim an industrial sewage lagoon in the County of Leduc under the Land Reclamation Program. Data showed the lagoon sludges to contain low levels of contaminants considered to be moderately hazardous. Landfarming was selected as the most cost effective method of rendering the sludge non-hazardous. Extra safety precautions were taken to protect workers on site. During the planning phase, the chemical characteristics of the sludge, and the precautions required to protect workers, were considered to be the major obstacles to success. However, the physical soil characteristics created by the sludge caused the greatest reclamation problems.

Additional Keywords: priority pollutants, metals, EC, SAR.

Introduction

The Nisku industrial sewage lagoon, located 10 km south of Edmonton (Figure 1) in the County of Leduc, became operational in 1976/77. The lagoon had sewage trucked to it from holding tanks at each individual property in the Nisku Industrial Park. The lagoon was designed to hold one year's contribution of sewage, with subsequent disposal of supernatant to Black Mud Creek which enters the North Saskatchewan River upstream of the City of Edmonton's Rossdale Water Treatment Plant.

The County did not permit the disposal of industrial by-products or chemical wastes into the lagoon; however, the County did not monitor dumping at the lagoon. As a result, an accumulation of petroleum products began to become a problem by 1980.

In 1981, Alberta Environment requested the County improve the operation of the lagoon. As a result, a caretaker was hired and better monitoring was instituted. In 1984, it was felt that the lagoon was biologically toxic. Chemical treatment with aluminum sulfate was carried out prior to allowing the supernatant to be released to Blackmud Creek.

In June 1985, the County approached the Land Reclamation Division of Alberta Environment with a

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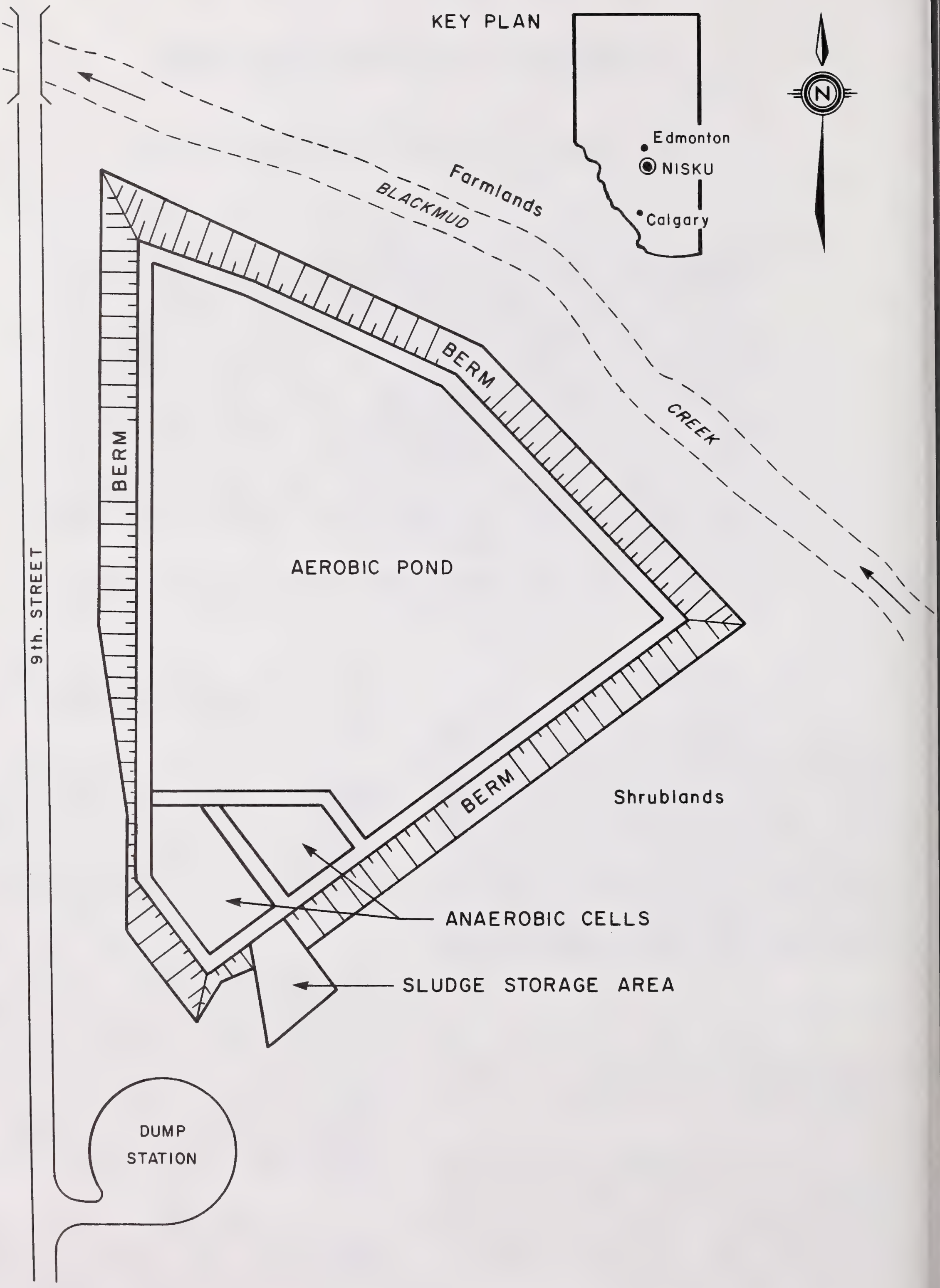

FIG.I LAYOUT OF NISKU INDUSTRIAL SEWAGE LAGOON

request to reclaim the sewage lagoon which was to be abandoned in September 1986. The Division determined that the project met the criteria for inclusion in the Heritage Savings Trust Fund Land Reclamation Program.

Site Description

The 4.8 ha Nisku Sewage Lagoon is located in the northeast corner of the Nisku Industrial Park. The site is bordered on the north and east sides by Black Mud Creek, on the west side by 9th Street, and on the south side by an area of shrub and grass. The lagoon consisted of two anaerobic cells (approximately 58 m x 30 m and 46 m x 30 m), one triangular shaped aerobic cell (approximately 238 m x 201 m x 128 m), and one sludge storage pit (approximately 32 m x 27 m). The average depth of the anaerobic cells was 3.4 m, the aerobic cell 3 m and the sludge pit 1.8 m.

In October 1986, prior to commencement of any work, samples of the sludge were taken from one of the anaerobic cells, the aerobic cell, and the sludge storage pit and submitted for analysis of phenols and polycyclic aromatic hydrocarbons (PAHs). The samples were dried at room temperature and soxhlet extracted using dichloromethane (DCM) for 12 hours. The extracts were partitioned and further extracted to generate an acid fraction and a base/neutral (B/N) fraction. The B/N fraction required further clean-up on alumina to generate an aromatic (PAH) fraction. The PAH fraction and the acid fraction were then injected for analysis by gas chromatography/flame ionization (GC-FID) and followed by GC/MS analysis for target EPA phenols and target EPA PAHs. Subsequent generation of mass spectra and NBS library search was completed to characterize the major non-target acids and aromatics. The data obtained indicated the presence of a variety of organic compounds that may be considered to be moderately hazardous (Table 1).

Following review of these data, a further set of sludge samples from one of the anaerobic cells was obtained and analyzed for metals (3 samples) and EPA priority pollutants (1 sample). The metals were extracted with an aqua regia digest and assayed by ICP. The EPA priority pollutant sample was extracted and analyzed according to the EPA method 625S (Haile and Lopez-Avila 1984). This method generates four base/neutral fractions which are a result of a florisil clean-up and one acid fraction which is cleaned up through gel permeation chromatography (GPC). GC/MS total ion chromatograms (TIC) of all the fractions were provided. Table 2 lists the priority pollutants identified in the sludge.

Significant metals (mg/kg dry weight basis) in the sludge included: Al (12,900 - 19,100); Ba (287 - 563); Cd (less than 11.2); Cu (30 - 398); Pb (31 -1620); Mo (2 - 13); and, Zn (106 -1760).

Reclamation Plan and Safety Precautions

The Division's standard practice when reclaiming sewage lagoons is to drain any water from the cells, use a dozer to push in the lagoon berms, displacing the sludge from the bottom of the cells, respread sludge on the levelled berm material, replace topsoil (if available), and seed the site. In the case of the Nisku lagoon, the presence of the organic compounds, coupled with the location of the site next to the Blackmud Creek and an adjacent farm, necessitated some changes.

In consultation with various authorities within Alberta Environment, it was decided that a landfarming operation would be the

Table 1. Compounds identified in sludges at the Nisku sewage lagoon. All values in mg/kg (wet weight basis).

Compound	Anaerobic Cell	Aerobic Cell	Sludge Storage
Naphthalene	5	5	0.11
Methyl Naphthalene	60	45	NP
Dimethyl Naphthalene	100	100	NP
Trimethyl Naphthalene	90	120	16
Methyl Ethyl Naphthalene	15	15	NP
Fluorene	18	13	1.3
Methyl Fluorene	170	160	18
Dimethyl Fluorene	80	40	2
Phenanthrene	105	90	NP
Methyl Phenanthrene	220	250	20
Dimethyl Phenanthrene	60	80	4
Trimethyl Phenanthrene	15	20	2
C_{14} to C_{18} Fatty Acids	6000	1700	770
Aliphatic Compounds	300	600	330
Methyl Dibenzofuran	40	30	NP
Dibenzothiophene	50	45	NP
Methyl Dibenzothiophene	80	80	NP
Dimethyl Napthothiophene	70	60	20
1,1' Biphenyl	15	NP	NP
Methyl Biphenyl	45	NP	NP
Pentachlorophenol	NP	6	1.8
Phenol	NP	NP	0.14
3 Unidentified Aromatic S Compounds	NP	NP	23
Unidentified PAH's	NP	NP	40

NP - chemical not present in the sample

Table 2. EPA priority pollutants identified from one of the anaerobic cells at the Nisku sewage lagoon. All values in mg/kg (wet weight basis).

Compound	Concentration	Compound	Concentration
Naphthalene	86.3	Dibutyl Phthalate	3.8
Phenanthrene	25.1	Bis(2-ethylhexyl) Phthalate	44.3
Fluorene	13.8	Phenol	0.5
Fluoranthene	1.0	2,4 Dimethyl Phenol	0.4
Butyl Benzyl Phthalate	2.6		

most cost effective method of rendering the sludges non-hazardous. A decision was made to fence the entire property to prevent unauthorized access and exposure to the sludge. In addition, signs were posted indicating the site contained potentially hazardous materials.

Lagoon water was tested for contaminants and a decision was made that the low levels found, coupled with the low volume of water present, would permit discharge of the water into the adjacent regional sewer system. The sewage treatment plant operators were notified of the water chemistry and water volumes being added to the system.

Due to the moderately hazardous nature of the sludge, a number of safety precautions were necessary. The precautions required by the Alberta Environment Occupational Health and Safety Officer were: (1) disposable coveralls; (2) rubber boots; (3) rubber gloves; and, (4) respirators complete with dust and organic vapour filters. There was to be no eating, drinking, or smoking on the site.

After consultation, the Alberta Occupational Health and Safety Office recommended the use of full face respirators until the levels of emissions were known. Occupational Health and Safety also required facilities for the crew to change into their protective equipment and be able to wash up prior to breaks and leaving the site. In addition, all construction equipment was to be thoroughly steam cleaned and have air filters changed prior to leaving the site.

As required, operations commenced using the full face respirator. However, problems with condensation on the interior of the glass reduced visibility below acceptable limits. Despite treatments with antifogging solution, applied and dried by various methods, the problem persisted.

Measurements of the levels of emissions on the site (Draeger polytest) indicated the full face respirators were not necessary so permission was granted by the Alberta Environment Occupational Health and Safety Officer to use a half mask with filters for toxic dust and organic vapours, and goggles. This eliminated the visibility problem.

Reclamation and Landfarming Operations

In order to reduce the costs of protective equipment and steam cleaning, it was decided to complete the reclamation with the minimum amount of equipment, as follows: (1) D6C Dozer with wide pads and winch; (2) D8H Dozer with ripper; and, (3) TS14 Motor Scraper.

Reclamation of the lagoon commenced on November 12th, 1987 with the equipment squeezing and then landscaping the aerobic cell. When this was completed, the two anaerobic cells were completed by the same method. The sludge pit was then squeezed and landscaped. After landscaping and spreading of the sludge was completed, containment dikes, interceptor ditches and a sump were constructed to retain surface drainage on-site. Work was completed on December 10th. On December 11th, the machines were steam cleaned and, along with the site trailer, were moved off-site.

At the end of May 1988, following spring thaw and surface subsidence, additional recontouring work was undertaken using D6D and D3 dozers. By July of that year, a considerable volume of water had accumulated in the sump and the interceptor ditches. The water was sampled, analysed and found to be of acceptable quality, and so was pumped into the regional sewer system. The site was then harrowed to help dry out the surface and fertilized to enhance microbial degradation of organics in the sludge. Difficulties were encountered in some of the wetter areas which resulted in the tractor becoming stuck in several spots.

By the end of July, the surface was very dry except in the areas where the tractor had previously gotten stuck. A 350B wide pad dozer was brought in to spread the material in these areas to enhance drying.

The site was chisel-plowed and fertilized again in late August 1988 and accumulated water was again pumped from the sump and ditches into the regional sewer system. The drainage ditches were also harrowed in an attempt to improve drainage and to spread the sludge in the ditches onto the site. The site was given a final disc-harrowing in early October.

Each time the site was worked, all equipment was steam cleaned prior to leaving the site. All overalls, mask filters and air filters were left on-site for later disposal.

Results and Discussion

In mid-October, 1988, surface soils (0 to 15 cm) were again sampled for metals and EPA priority pollutants. As these analyses are extremely expensive, only one sample would be processed; it was therefore decided to collect four subsamples from areas of obvious contamination, (i.e., pure sludge and obvious salt crusts) in order that the worst-case scenario would be determined. EM-38 readings taken on-site, coupled with evident salt crusts, led to analysis for EC and SAR as well.

Only two of the EPA priority pollutants were found in the sample (expressed on a wet weight basis): Bis (2-ethylhexyl) phthalate (2.3 mg/kg) and dioctyl phthalate (2.4 mg/kg). Neither of these is considered hazardous, even at much higher concentrations (Naylor and Loehr 1982a,b).

Care should be taken when evaluating the results of both EPA priority pollutant analyses as there was only one sample taken in each case. In particular, the results of the second sampling do not necessarily mean that the landfarming operation has successfully degraded the pollutants shown in Table 1. Many more samples would be required to prove this hypothesis; however, the costs to do these analyses precludes a massive sampling program.

Significant metals (total levels as mg/kg dry weight) included: Al(15,300); Ba(483); Cu(36.3); Pb(58); and, Zn(133). Diethylenetriamine pentacetic acid (DTPA) extracts of the same samples (McKeague 1978), which test for plant available metals, showed much lower levels (i.e. in mg/kg on a dry weight basis, Zn - 10.9 and 12.1 vs 133; Pb - 13.7 and 16.1 vs 58; Cu - 4.3 vs 36.3) than those found in the total extractable analysis. However, even the total values are lower than those specified in Alberta's sludge application guidelines (McCoy et al. 1982). The sludge/soil mixture is therefore acceptable from the standpoint of metal content.

Of greater concern for future reclamation are the results of the particle size and salinity analyses. The samples were classed as clay loam to clay with a saturation percentage of 83%. The materials had EC values of 4.1 to 6.4 dS/m and SAR values of 7.2 to 8.4, which render them Fair to Poor as subsoils (ASAC 1987). Soluble sodium was present at 26.0 meq/L to 41.0 meq/L.

Conclusions and Future Work

In assessing the best methods for reclaiming this site, Alberta Environment decided to err on the side of safety. Extra precautions were taken on-site to protect workers and to reduce the likelihood of unauthorized personnel being exposed to the sludge. Results of the soils analysis one year after reclamation commenced appear to indicate a reduction in the potential hazard posed by the sludge. This apparent reduction may be due to biodegradation of organic compounds as a result of the landfarming operation or to a dilution of the sludge contents through mixing with soil, or a combination of both. It is important to note, however, that the limited sampling does not allow firm conclusions as to the extent of degradation. For this reason, the fence will remain in place for several more years to ensure unauthorized access is restricted.

During the planning phase of this project a great deal of attention was given to the organic constituents in the sludge and their potentially hazardous properties. However, once landfarming operations commenced, the addition of the sludge to the soil produced other problems which may, in the longer term, be more difficult to address than the organics.

The high clay content of the sludge/soil mixture leads to the formation of surface crusts when dry and sealing when saturated, resulting in ponding of water. The surface crust (approximately 10 cm deep) slows the drying process below the surface, leaving visually dry areas soft enough underneath to trap the equipment used in the landfarming operation. This necessitated bringing in construction equipment a number of times to expose the subsurface material for drying, and thus greater expense.

The salinity and sodicity of the surface materials, coupled with low organic matter levels and a minimal amount of topsoil available to cover the reclaimed area poses future problems. Amendments such as manure, straw or peat are being considered to increase organic matter content, and hopefully, to further enhance the biodegradation of the remaining organic compounds. Gypsum or other calcium sources may be required to improve the chemistry of the soil to ensure adequate plant growth.

Work in 1989 will include recontouring the site to enhance drainage, organic matter additions to enhance degradation of the remaining organics and to improve soil drainage, continued landfarming (tillage plus fertilization), respreading of available topsoil, and reseeding.

Work in 1990 and later will depend on the results of chemical analyses and growth of the crop planted in 1989.

In summary, landfarming appears to have resulted in an acceptable reduction of the hazard posed by the sludge. However, the Division will continue the landfarming operation for one more year and will maintain restricted site access.

The physical properties and inorganic chemistry of the sludge/soil mixture have posed more operational reclamation difficulties than the organics have.

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RELATIONSHIPS AMONG SOIL DEPOSITION PATTERNS, SOIL PHYSICAL AND CHEMICAL PROPERTIES, AND PLANT METAL UPTAKE ON AN ABANDONED ZINC-LEAD TAILINGS POND[1]

by

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Abstract. A 50 year-old abandoned tailings pond from a zinc-lead mill near Pecos, New Mexico, was sampled to determine relationships among soil deposition patterns, physical and chemical properties of the tailings and surface deposited soils, plant community development, and Cu, Zn, Pb, and Cd concentrations in plant tissue. Percentage silt and clay and concentrations of Cu, Zn, Pb, and Cd in surface soils were highest at the lower end of the pond indicating accumulation of both water-transported fine materials and heavy metals. The degree of vegetation development was greatest at the lower end of the pond, was positively related to soil organic matter, and may have contributed to metal accumulation. Plant tissue concentrations of Cu, Zn, Pb, and Cd were highly correlated to soil concentrations and were at potentially toxic food-chain levels for some of the metals. Potential food-chain movement and bioaccumulation of the metals and methods of reclaiming the site are discussed.

Additional Key Words: food-chains, mine tailings, Cu, Cd

Introduction

Successful reclamation of tailings ponds that contain toxic elements depends on a thorough knowledge of the environmental and edaphic conditions that exist on the site at the time reclamation is initiated. Equally important but more difficult to acquire is information about the processes that occur on the site after it has been reclaimed, such as soil deposition or erosion, soil development, plant and animal succession, movement of potentially toxic elements, and incorporation or accumulation of potentially toxic elements in food-chains. Information on these processes can provide valuable insights into the development of the best reclamation methods. It can help to determine the optimal shape of the site, the depth and type of surface materials, species selection and planting or seeding methods, postreclamation land uses, and monitoring methods.

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The upper tailings pond within the State of New Mexico's Burt Clancy Fish and Wildlife Management Area presented a unique opportunity to study relationships among soil deposition patterns, soil and vegetation development, and heavy metal concentrations in soils and plants 50 years after abandonment. The tailings within the pond were from a zinc-lead mill and were high in elements such as Pb, Zn, Cd, and Cu (Grant 1988). They also contained high concentrations of sulfuric compounds and, consequently, were characterized by low pH, i.e., 3-4. An ephemeral stream ran through the tailings pond and had resulted in extensive flooding and deposition of sediment on top of the original tailings. Distinct vegetation communities had developed on the site in the 50 years since abandonment.

This study examined the natural developmental processes that had occurred on the pond. We addressed several questions: (1) What were the patterns of soil deposition on the tailings pond and how were they related to topography? (2) What were the physical and chemical characteristics of the tailings and of the soils that were deposited over the tailings? (3) What was the relationship between soil characteristics, plant community development, and plant metal concentrations ? (4) What was the potential for food-chain movement and bioaccumulation of metals? Study results were the basis for recommendations for reclamation.

Methods

The 14-ha tailings pond was in Alamitos Canyon (T16N, R12E, S30) at an elevation of 2,182 m near Pecos, New Mexico. The vegetation surrounding the pond ranged from Colorado pinyon (Pinus edulis)/one-seed juniper (Juniperus monosperma) to ponderosa pine (Pinus ponderosa)/ gambel oak (Quercus gambelii) woodland (Gass 1983). Average annual precipitation was 40 cm, over one-half of which arrived from June through September. The geology of the ore that was processed in the zinc-lead mill was described by Stott (1931) and the milling process was detailed by Bemis (1932).

A grid system with nodes spaced 25 m apart was superimposed over the entire pond to facilitate sampling. Relative elevational differences at each of the 180 nodes on the pond's surface were determined using an engineer's level. The pond's area was determined by digitizing its boundary from an aerial photo.

Patterns of soil deposition and associated vegetation were determined from an initial survey of the soil and vegetation at each node within the grid. Soils were sampled with a 10-cm diameter auger to determine the depth to tailings, soil or tailings texture, and soil or tailings color. Vegetation was sampled adjacent to each node. Each species was assigned a cover code value that reflected percentage of aerial cover of a 0.25 m^2 rectangular quadrat: cover code percent 1 = < 1, 2 = 1-5, 3 = 6-15, 4 = 16-25, 5 = 26-35, 6 = 36-45, 7 = 46-55, 8 = 56-65, 9 = 66-75, 10 = 76-85, 11 = 85-95, and 12 = 95-100. The soil and vegetation survey was used to provide an initial characterization of the soil/ vegetation types on the pond. Six types were classified: (1) tailings (loamy sand/no vegetation); (2) sands or xeric meadow (loamy sands/blue grama [Bouteloua gracilis] - sand dropseed [Sporobolus cryptandrus]); (3) mesic meadow transition (sandy loam/ vegetation typical of both sands and mesic meadow); (4) mesic meadow (loam/ creeping bentgrass

[Agrostis stolonifera]); (5) wet meadow transition (loam - clay loam/vegetation typical of both mesic and wet meadow); and (6) wet meadow (clay loam/Baltic rush [Juncus balticus] - Kentucky bluegrass [Poa pratensis]). Each sample node was assigned a soil/vegetation type and a subset of nodes within each type was selected for collection of plant tissue and soil samples (N = 60).

Soil samples for physical and chemical analyses were collected at all 60 nodes. The depths sampled were dependent upon the depth of the soils deposited over the tailings. In general, these were 0-5, 15-25, 35-45, and the 10 cm increment above the tailings transition. Also, samples of surface tailings and tailings beneath each soil/vegetation type were collected. For the purposes of this paper, only the results from the tailings and the 0-5 cm samples of the soil/vegetation types will be discussed. Knowledge of the mining and milling process and a previous study of elemental concentrations on the pond (Grant 1988) indicated that Cu, Zn, Pb, and Cd posed the greatest environmental hazard and, thus, they were the main focus of this study. The initial study indicated low levels of available (DPTA-extractable) Cd; total concentrations of both Cd and Pb were determined for this study. All samples were analyzed for texture (Day 1973), organic matter (OM) (Schulte 1980), available P (Knudson 1980), exchangeable K and Mg (Carson 1980), pH (McLean 1980), cation exchange capacity (CEC) (Carson 1980), SO_4-S (Eik 1980), DTPA-extractable Mn, Fe, B, Cu, and Zn (Whitney 1980), and total Pb and Cd (EPA 1986). Soil analyses were performed by A and L Labs[3], Omaha, Nebraska.

Plant tissue samples (leaves and flowering stalks) were collected from three grass species for chemical analyses. Alkali muhly (Muhlenbergia asperifolia) occurred on all soil/vegetation types and was collected at each of the 60 nodes. Blue grama was sampled from sands and mesic meadow transition (N = 30), while creeping bentgrass was collected from mesic meadow, wet meadow transition, and wet meadow (N = 30). Elemental concentrations of two deep-rooted woody species, coyote willow (Salix exigua) and narrowleaf cottonwood (Populus angustifolia), were evaluated by collecting and analyzing leaf samples from six nodes at which they both occurred. Tissue analyses were performed by A and L Labs to determine concentrations of Cu, Zn, Cd, and Pb (AOAC 1984).

Before analyzing the data, the initial soil/vegetation types were refined based upon the results of the physical and chemical soil analyses and the plant species cover data. Differences in soil physical and chemical properties among soil/vegetation and differences in plant tissue concentrations of the various elements among soil/vegetation types and between species were determined from one- or two-way ANOVA.

Results and Discussion

Soil deposition patterns and, consequently, vegetation development were greatly influenced by the elevation gradient within the tailings pond and the effects of the ephemeral stream. The elevational change over the 900 m length of the pond was about 7 m with the steepest gradient in the upper portion of the pond (Figure 1). It appeared that the main stream channel had undergone periods of both aggradation and degradation but that it was currently downcutting, ranging from 1 to 2 m deep in the upper portion of the pond. Overland flow from adjacent hillsides onto the pond and sedimentation adjacent to the stream resulted in a patterned depositional surface at the upper end of the pond. The sand soil/vegetation type was primarily in this well-drained area (Figure 2). The lower end of the pond was characterized by significant deposition from both the stream and adjacent hillsopes. The wet meadow type occurred in the lowest area within the pond and experienced standing water during part of the year. The mesic meadow and meadow transitions were found at intermediate elevations or along the stream channel.

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[3] The use of trade or firm names in this paper is for reader information and does not imply endorsement by the U.S. Department of Agriculture of any product or service.

The tailings materials were characterized by uniformly low pH and high concentrations of total Pb and Cd and available Cu and Zn (table 1). Despite inherently high variability in tailings chemical and physical properties, tailings beneath the wet meadow type had significantly higher percentages of silt and clay and higher concentrations of Pb than tailings on the surface or beneath the sands type. Also, tailings beneath the wet meadow tended to have nonsignficantly higher concentrations of Zn, Cd, and Cu than other sites. Differences in the elemental concentrations may have resulted from differences in the tailings at the time of deposition. However, it is more likely that the lower end of the pond experienced an accumulation of both water-transported fine materials and associated heavy metals through time.

Physical and chemical soil properties (0-5 cm) of the different soil/vegetation types also indicated that there had been an accumulation of water-transported fine materials and of most elements, including the heavy metals, in the surface deposited materials at the lower end of the pond (table 2). Although pH approached neutral and was relatively constant across the pond, percentages of both silt and clay increased significantly toward the lower end of the pond. Percentage OM was significantly higher in the meadow types than in the sands or mesic meadow transition, but a similar trend did not exist for CEC. Concentrations of K, Mg, and B were significantly higher in the mesic meadow, wet meadow transition, and wet meadow than in the sands or mesic meadow transition, while the opposite was true for available P. In general, metal concentrations were lowest in the sands and mesic meadow transition, highest in the wet meadow transition and wet meadow, and intermediate in the mesic meadow.

Levels of metals in the surface deposited soils were influenced not only by transport and depositional processes, but also by properties of the metals, tailings, and soils. Concentrations of Cd, Zn, Cu, and Pb in the different surface soils relative to those in the tailings materials were predictable based upon their solubilities, that is $Cd \sim Zn > Cu >> Pb$. The proportion of metals in surface soils relative to tailings was higher for metals with higher solubilities (Cd and Zn) than for metals with lower solubilities (Cu and, especially Pb) (tables 1 and 2), although the exact nature of this relationship may have differed if the comparisons were based only on available instead of both available and total concentrations. Retention of metals was highly dependent on the pH, texture, and OM of the soils. In

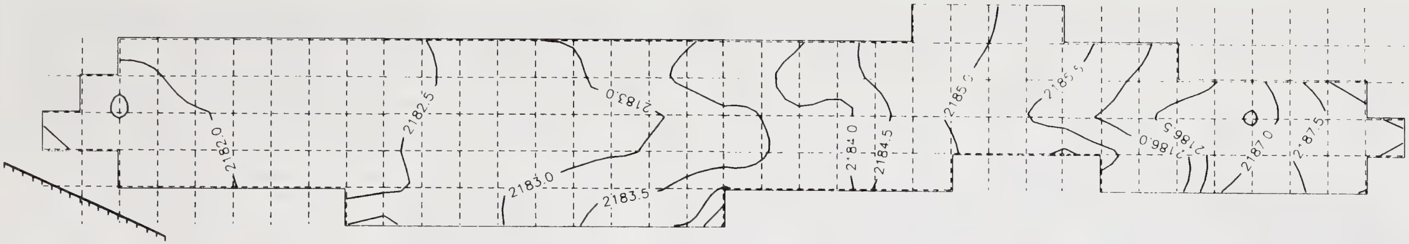

Fig. 1. Elevational change over the length of the tailings pond. Node distance is 25 m. Contour interval distance is 0.5 m.

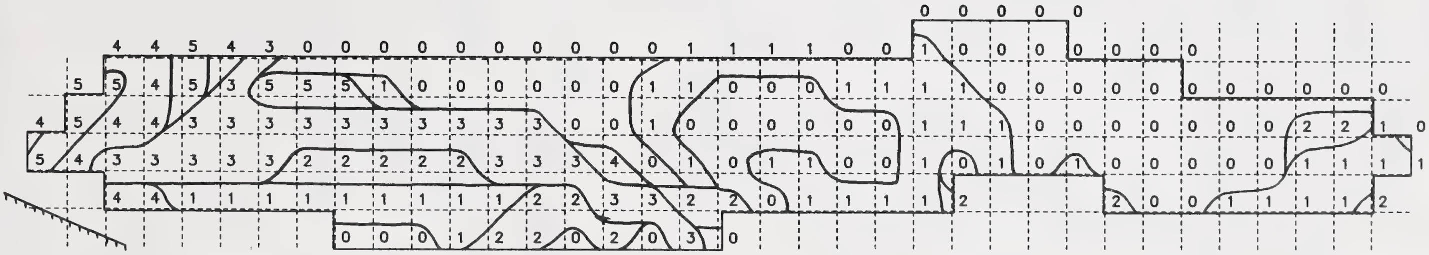

Fig. 2. Soil/vegetation types on the tailings pond. Numbers specify types: 0 = tailings, 1 = sands, 2 = mesic meadow transition, 3 = mesic meadow, 4 = wet meadow transition, 5 = wet meadow. Node distance is 25 m.

Table 1. Characteristics of tailings material at the surface and beneath the sands and wet meadow soil/vegetation types of an abandoned tailings pond.

Property	Surface tailings (n = 10)	Sands (n = 5)	Wet meadow (n = 3)
pH	3.1 ± 0.2[1]	3.3 ± 0.2	3.5 ± 0.5
CEC (meq/100 g)	42.6 ± 8.8	35.3 ± 14.8	29.4 ± 6.4
% Sand	66.4 ± 5.3 b[2]	69.2 ± 3.3 b	19.3 ± 7.7 a
% Silt	24.5 ± 5.2 a	20.4 ± 4.1 a	60.3 ± 5.2 b
% Clay	9.1 ± 1.2 a	0.4 ± 2.0 a	20.3 ± 5.5 b
Total Pb (mg/kg)	3626.1 ± 678.4 a	5123.6 ± 693.6 a	9393.7 ± 870.0 b
Total Cd (mg/kg)	0.8 ± 0.4	1.3 ± 0.6	8.9 ± 8.5
DPTA Zn (mg/kg)	45.7 ± 30.0	35.9 ± 22.3	241.9 ± 237.6
DPTA Mn (mg/kg)	6.9 ± 2.8	4.4 ± 3.4	2.0 ± 0.6
DPTA Fe (mg/kg)	372.0 ± 197.3	645.0 ± 538.9	93.0 ± 75.6
DPTA Cu (mg/kg)	42.6 ± 25.6	24.8 ± 10.1	103.8 ± 98.6
So_4-S (mg/kg)	95.6 ± 0.4	95.8 ± 0.9	96.0 ± 0.6

[1] Values are means ± 1 S.E.

[2] Different letters indicate significant differences among soil/vegetation types where shown (Fisher's Protected LSD; $p < .05$).

Table 2. Physical and chemical properties of the 0-5 cm soil samples from 5 soil/vegetation types on an abandoned tailings pond.

Property	Sands (n = 18)	Mesic meadow transition (n = 8)	Mesic meadow (n = 11)	Wet meadow transition (n = 9)	Wet meadow (n = 5)
OM (%)	[1] 1.3 ± 0.1 a[2]	1.2 ± 0.1 a	3.0 ± 0.3 b	3.4 ± 0.3 b	3.6 ± 0.4 b
CEC (meq/100g)	12.1 ± 1.5 a	18.5 ± 3.7 bc	23.1 ± 2.5 c	16.9 ± 1.3 abc	15.3 ± 1.1 ab
pH	7.1 ± 0.3 a	6.8 ± 0.5 a	6.8 ± 0.1 a	6.5 ± 0.4 a	6.8 ± 0.3 a
% Sand	73.9 ± 2.7 c	72.3 ± 2.3 c	31.6 ± 4.0 b	18.7 ± 1.6 a	21.6 ± 2.2 ab
% Silt	16.8 ± 2.4 a	17.3 ± 1.6 a	49.6 ± 3.4 b	43.0 ± 2.1 b	41.0 ± 1.8 b
% Clay	9.2 ± 0.5 a	10.0 ± 0.8 a	18.7 ± 2.3 b	38.2 ± 2.2 c	37.4 ± 3.3 c
P (mg/kg)	4.9 ± 1.3 b	4.0 ± 0.4 b	1.5 ± 0.2 a	1.4 ± 0.2 a	1.4 ± 0.4 a
K (mg/kg)	80.0 ± 7.6 a	78.0 ± 13.1 a	151.4 ± 9.7 b	166.4 ± 12.6 b	175.0 ± 23.5 b
Mg (mg/kg)	46.9 ± 4.0 a	90.3 ± 17.2 a	241.8 ± 30.2 b	213.3 ± 18.3 b	213.3 ± 14.8 b
So_4-S (mg/kg)	84.8 ± 5.4 a	96.3 ± 0.4 a	96.1 ± 0.4 a	92.8 ± 3.4 a	96.0 ± 0.5 a
B (mg/kg)	0.8 ± 0.0 a	0.9 ± 0.1 a	1.1 ± 0.1 b	1.1 ± 0.0 b	1.2 ± 0.1 b
Total Pb (mg/kg)	530.8 ± 67.6 a	515.3 ± 67.1 a	2644.2 ± 290.7 b	5199.2 ± 381.2 d	3899.4 ± 765.5 c
Total Cd (mg/kg)	1.5 ± 0.2 a	1.3 ± 0.5 a	4.7 ± 0.4 b	6.7 ± 0.8 bc	9.3 ± 2.9 c
DPTA Zn (mg/kg)	36.5 ± 5.7 a	49.3 ± 13.5 a	165.1 ± 14.9 b	190.7 ± 12.7 bc	231.8 ± 41.3 c
DPTA Cu (mg/kg)	13.0 ± 1.8 a	15.1 ± 2.4 a	84.4 ± 6.1 b	122.9 ± 7.2 c	114.0 ± 4.9 c
DPTA Mn (mg/kg)	5.2 ± 0.3 a	6.0 ± 2.2 ab	7.9 ± 0.8 b	7.9 ± 0.8 b	8.6 ± 2.0 b
DPTA Fe (mg/kg)	29.2 ± 8.8 a	53.3 ± 32.9 ab	81.5 ± 6.5 b	92.0 ± 13.4 b	76.0 ± 20.3 ab

[1] Values are means ± 1 S.E.

[2] Different letters indicate significant differences among soil/vegetation types (Fisher's Protected LSD; $p < .05$).

general, availability of Cd, Zn, Pb, and Cu decreases with increases in pH and percentage clay and OM. At higher pH levels metals are precipitated as insoluble compounds. The near neutral pH of the soils in this study resulted in lower availability of the metals but higher retention than would be expected in lower pH soils. Metals can be adsorbed onto clay surfaces depending on the exchangeable cation present on the clay surface and the metal species. They can also form stable complexes with OM, although the stability of these complexes may be greater for Cu and Pb than for Cd or Zn (Safaya et al. 1987). The higher percentages of OM and clays at the lower elevations of the pond in the mesic meadow, wet meadow transition, and wet meadow indicated a greater capacity for retention of the heavy metals.

The amount and type of vegetation development can affect OM and elemental accumulation in surface soils. Aerial vegetation cover on the pond was 14, 32, 44, 62, and 61 percent for the sands, mesic meadow transition, mesic meadow, wet meadow transition, and wet meadow soil/vegetation types, respectively. Higher vegetation production results in larger amounts of above- and below-ground litter and may, ultimately, result in greater turnover of elements and in higher levels of OM (Antonovics et al. 1971). Many plant species take up certain mineral nutrients in excess of nutritional needs and will also take up nonessential elements, often in large amounts. When the plants die and their litter is decomposed, the elements are released back into the soil and are usually concentrated near the surface. Over time, these processes can contribute to the redistribution or accumulation of elements in soils.

Plant tissue concentrations of Pb, Cd, Zn, and Cu for alkali muhly were highly correlated with soil concentrations of those elements in the different soil/vegetation types. Linear and nonlinear regression resulted in r^2 values of 0.99, 0.97, 0.90, and 0.99 for total Pb and Cd and available Zn and Cu, respectively. The relationships between soil and plant tissue correlations were reflected in the analyses of just the plant tissue concentrations (table 3). Concentrations of Pb in alkali muhly on the sand type did not differ from those on the mesic meadow transition but were significantly lower than those on the other types. Also, concentrations of Cd in alkali muhly on the wet meadow were similar to those on the wet meadow transition but were significantly higher than those on other types. Plant tissue concentrations were often highly variable within soil/vegetation types. Despite apparent trends, there were no significant differences among the types in blue grama or creeping bentgrass for any of the metals or in alkali muhly for Zn or Cu. Also, there were no significant differences between species.

Concentrations of Zn and Cd in the two deep-rooted species, coyote willow and narrowleaf cottonwood, were extremely high when compared to the three grasses (table 4). In

Table 4. Elemental concentrations (mg/kg) in Salix exigua and Populus angustifolia on an abandoned tailings pond.

Element	Salix exigua (n = 7)	Populus angustifolia (n = 6)
Pb	15.32 ± 7.08[1]	11.99 ± 8.42
Zn	1041.00 ± 140.68	1092.83 ± 147.23
Cd	8.66 ± 1.38	21.95 ± 8.30
Cu	11.86 ± 2.02	8.33 ± 1.20

[1] Values are means ± 1 S.E.

Table 3. Elemental concentrations (mg/kg) of 3 grasses on 5 different soil/vegetation types on an abandoned tailings pond.

	M. asperifolia	*B. gracilis*	*A. stolinifera*	*M. asperifolia*	*B. gracilis*	*A. stolinifera*
	Pb			Zn		
Sands	24.7 ± 19.0 (17)a	16.7 ± 12.7 (16)a		103.1 ± 59.5 (18)a	118.1 ± 55.7 (16)a	
Mesic meadow transition	36.8 ± 38.8 (8)ab	18.6 ± 9.3 (6)a		110.9 ± 73.4 (8)a	113.7 ± 39.7 (6)a	
Mesic Meadow	57.9 ± 26.1 (11)b		62.3 ± 41.8 (11)a	148.0 ± 51.7 (11)a		136.6 ± 59.6 (11)a
Wet Meadow transition	69.0 ± 64.2 (5)b		37.6 ± 28.6 (9)a	127.6 ± 45.8 (9)a		154.0 ± 60.0 (9)a
Wet Meadow	68.6 ± 26.7 (9)b		38.9 ± 21.9 (5)a	159.4 ± 80.9 (5)a		154.0 ± 46.8 (5)a
	Cd			Cu		
Sands	0.4 ± 0.2 (17)a	0.2 ± 0.2 (16)a		11.2 ± 4.7 (18)a	9.4 ± 2.4 (16)a	
Mesic meadow transition	0.4 ± 0.5 (8)a	0.4 ± 0.4 (6)a		12.2 ± 8.4 (8)a	8.7 ± 3.1 (6)a	
Mesic meadow	0.7 ± 0.6 (11)a		0.6 ± 0.4 (11)a	14.1 ± 5.0 (11)a		11.4 ± 4.1 (11)a
Wet meadow transition	0.9 ± 0.6 (9)ab		1.0 ± 0.6 (90)a	14.8 ± 10.9 (9)a		10.5 ± 3.0 (9)a
Wet meadow	1.5 ± 1.5 (5)b		1.2 ± 0.7 (5)a	13.4 ± 3.4 (5)a		10.6 ± 1.7 (5)a

[1] Values are means ± 1 S.E., n is in parenthesis.

[2] Different letters indicate significant differences among soil/vegetation types within species (Fisher's Protected LSD; $p < .05$).

contrast, concentrations of Pb were generally lower than those of the grass species, and concentrations of Cu were similar to those of the grasses. The higher Pb concentrations in the grasses may have resulted, in part, from surface contamination of Pb from the soil.

Lead, Zn, Cd, and Cu are toxic to both plants and animals at high concentrations. Although Zn and Cu are essential nutrients for plants and animals, Pb and Cd have no known function in living organisms. Determining the concentrations at which these metals become toxic is difficult for several reasons: (1) different sampling and extraction methods have been used to obtain reported values; (2) natural variability of these elements in soils is high; and (3) concentrations at which these elements become toxic varies greatly among individual species of both plants and animals. However, to evaluate potential toxicity it is necessary to establish tolerance limits. Table 5 attempts to present reasonable values for the ranges of concentrations common in plant leaves and for suggested maximum concentrations in plant tissue for plants and for livestock forages. Elevated plant tissue concentrations for Pb and Cd existed in the three grass species. Tissue concentrations of Cu were within normal ranges, while those for Zn were at the upper end of the range for both alkali muhly and creeping bentgrass and were greatly elevated for coyote willow and narrowleaf cottonwood. Plant tissue concentrations of Pb exceeded or were at the upper range of maximum suggested values for all species in all soil/vegetation types but were within the upper limits for the other metals for the grasses. Levels of Zn and Cd were much higher than suggested maximums for the two woody species.

There were no visible signs of plant toxicity within any of the soil/vegetation types. However, the high concentrations of metals may have had negative effects on plant metabolic processes that were not visually apparent. Although plant leaf concentrations of Zn and Cd are usually linearly related to soil concentrations, leaf concentrations of Cu and Pb may not reflect soil levels, and root concentrations may be better indicators of toxicity. Certain plant species are capable of rapidly adapting to high concentrations of metals, and tolerant species may accumulate high levels of metals in the roots without subsequent translocation to the shoots. Excess Cu, Cd, Zn, or Pb can decrease root and shoot growth in both tolerant

Table 5. The range in elemental concentrations (mg/kg) of Pb, Zn, Cd, and Cu common in plant leaves and suggested maximum concentrations for plants and for livestock forages.

Element	Plant leaves	Max plants	Max forages
Pb	0.1 - 5.0[c]	10 - 20[bc]	30[e]
Zn	15 - 150[bc]	400[d]	300[e]
Cd	0.2 - 0.8[a]	3[a]	0.5[e]
Cu	5 - 15[b]	16 - 20[b]	25[e]

[a] Allaway (1968).
[b] NEC-28 (1985).
[c] Mehlstad (1973).
[d] Marschner (1986).
[e] NRC (1980).

and nontolerant species by interfering with metabolic processes such as respiration and photosynthesis (Bingham et al. 1975). The high metal concentrations may have resulted in total exclusion of sensitive species, especially in the mesic meadow, wet meadow transition, and wet meadow.

Because the pond is within a state wildlife management area, potential food-chain movement and bioaccumulation of metals in wildlife are of concern. While most animals can tolerate high amounts of Zn, mammals have low tolerance for both Cd and Cu, and Pb and Cd act as cumulative toxins. High variation in trace metal accumulation by different animals is to be expected from their different and highly specialized diets, and seasonal influences on food availability and dietary metal concentrations (Hunter et al. 1987). Because of the tendency for metals to concentrate in higher food-chain levels, metal concentrations in plant tissue should be used as risk indicators only for strictly herbivorous species. The maximum suggested values in forages in table 5 are for the lowest given for livestock (NRC 1980) and are presented here only to provide general guidelines. The three grasses were well within suggested limits for Zn and Cu in livestock forages, while the woody species greatly exceeded the levels given for Zn. Cd was within suggested limits for all but the two woody species. Excessive Pb levels were present in alkali muhly and creeping bentgrass in the mesic meadow transition, mesic meadow, wet meadow transition, and wet meadow. Although surface contamination may have increased plant Pb and Cd values, these levels accurately reflect the amounts ingested by animals.

The results of this study have strong implications for the reclamation of the tailings pond. The depositional processes on the site result in an accumulation of water-transported sediments and heavy metals and organic matter that exacerbate the accumulation of those metals in the meadow areas at the lower end of the pond. To prevent these processes from occurring, it will be necessary to reroute the stream so that it no longer flows over the tailings pond in an uncontained manner. This will result in more xeric site conditions and will necessitate revegetation of the meadow types with species adapted to xeric conditions. High concentrations of Pb were found in the mesic meadow, wet meadow transition, and the wet meadow that were reflected in plant tissue concentrations of alkali muhly and creeping bentgrass. Elevated levels of Cd and Cu were present in the wet meadow transition and the wet meadow, but these levels were not reflected by plant tissue concentrations in the grass species. The deep-rooted species, coyote willow and narrowleaf cottonwood, had high levels of Cd and Zn. This indicates the need to topsoil the mesic meadow, wet meadow transition, and the wet meadow in addition to the tailings materials prior to revegetation of the site with noncontaminated materials from offsite. Currently available topsoil materials are similar to the soils of the sand soil/vegetation type, and revegetation species can be selected from those that occur on the sand type. Deep-rooted woody species should not be seeded and should be removed from the site if they colonize naturally.

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BIOREMEDIATION: INNOVATIVE APPLICATIONS OF AN ESTABLISHED TECHNOLOGY[1]

by

Jim League and John Bogart[2]

Abstract. Bioremediation of organic wastes, pioneered by John Bogart, has been refined and modified extending the range of materials treated and decreasing the required treatment time. Materials degraded by biological methods include: oil and grease, petroleum hydrocarbons, creosote, pentachlorophenol, pesticides, PCB's, refinery wastes, and chlorinated solvents. These materials have been treated in waste sludges, contaminated soils, contaminated groundwater, process waters, and process sludges.

Additional Key Words: bioremediation, soils, sludges, organics, PNA, PCB, chlorinated solvents.

Introduction

Landfarming, long a staple in oil field and refinery remediation projects, was the genesis of bioremediation. Bioremediation has been expanded to encompass the remediation of sludges and groundwater. Traditional landfarming has undergone significant enhancements which have produced kinetic rates that are orders of magnitudes greater than those previously attained.

John Bogart, a bioremediation pioneer, has produced innovative biotechnology developments. These advances have extended both the range of compounds amenable to biotechnology and the rates of degradation achieved. These innovations include a patented technology, liquid-solids contact digestion; enhanced landfarming techniques; and hardware used in the remediation of groundwater and contaminated soils.

Materials degraded include oil and grease, petroleum hydrocarbons, creosote, pentachlorphenol, pesticides, PCB's, and refinery wastes. Ideal candidates for remediation include drilling muds, production pits, and oil shale residues. Spill sites have also been successfuly restored.

Bioremediation is practical for sludges, contaminated soils, contaminated groundwater, process waters, and process sludge from industrial waste water treatment systems. Bioremediation has been demonstrated to be technically feasilble. Bioremediation is cost-effective, with unit prices often less than one-half of alternative remedies.

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[1] Paper presented at the conference Reclamation, A Global Perspective, held in Calgary, Alberta, Canada August 27 - 31, 1989.

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Landfarming

Landfarming of contaminated materials has come into difficult days. Some practitioners of the art/science have produced a general skepticism regarding all bioremediation. The methods employed by these groups have simply failed to achieve detoxification at best, and increased the volume of contaminated material at worst. Some regulators feel that the "land ban" has doomed landfarming to join blood letting as an abandoned practice.

The purpose of this report is not to defend nor bemoan the status of landfarming, but to report on innovative alternatives to the traditional practice. Much land-treatment is continuing and with reasonably satisfactory results. Some of these practices will be surveyed.

Several land-treatment facilities, under the direction of John Bogart, have achieved acceptable, reproducible results on woodtreating wastes. All of these systems were operated inside the existing impoundment and on a clay liner. The USEPA is requesting (mandating?) synthetic liners to assure the policy of "no migration" in accordance with the Resource Conservation Recovery Act (RCRA).

The Bogart system incorporates inoculation with natural organisms into a program of active aeration and soil moisture control. Some representative data from landfarming operations is summarized in Table 1.

Other problems, in addition to the concern of "migration" of contamination, complicate land-treatment projects. The kinetic rate of biodegradation in a "moist" environment is slow, at best. If the matrix becomes totally dry the bacteria become inactive. Maintaining optimum moisture levels is difficult if not nearly impossible in a large scale operation. Too much moisture produces anoxic or anaerobic conditions and is as detrimental to bioactivity as too little moisture. Weather, then, plays a vital, unpredictable, and virtually uncontrollable role in solid state biotreatment.

Table 1
Landfarm Data

SITE	PARAMETER	INITIAL (mg/kg)	FINAL (mg/kg)	TIME
A	K-001	6,959	58	1 month
A	Pentachlorophenol (PCP)	1,291	9.3	1 month
B	K-001	6,582	210	1 month
B	Pentachlorophenol (PCP)	1,184	ND	1 month
C	K-001	12,561	835	5 weeks
C	Pentachlorophenol (PCP)	1,336	104	5 weeks
D	Benzene	38.1	.003	3 weeks
D	Toluene	266.9	<.001	3 weeks
D	Ethylbenzene	74	.002	3 weeks
D	Dichlorobenzene	29.1	.011	3 weeks
D	Xylene	303.1	.03	3 weeks
E	K-001	2,050	106	1 month

Besides being slow and unpredictable, landfarming also suffers from the "hot" spot syndrome. One area may be decontaminated to Best Demonstrated Available Technology (BDAT) levels or below while a neighboring sector remains extremely contaminated. Verification sampling programs must be carefully devised and implemented to assure satisfactory remedial actions.

Liquid/Solids Contact Process

The twin problems of moisture control and lack of homogeneity were overcome by the liquid/solids contact (LSC) process. Producing an aerated slurry coincidentally addresses both problems. The constantly mixed slurry is homogeneous. This insures a uniform degradation throughout the contaminated matrix.

Aerating the slurry provides high levels of oxygen required for the biological oxidative processes. Reaction rates are maintained at a high level in this aerobic environment. Appropriate biological enhancements such as nutrients, pH control, emulsifiers, and even co-metabolites are easily and conveniently administered in a uniform manner.

The LSC has successfully reduced both volume and toxicity of 50% organic sludges classified as K-001 or woodtreating wastes consisting of creosote and pentachlorophenol. One specific project in Sweetwater, Tennessee, involved 4500 cubic yards of sludge. The residuals, following degradation, were estimated to be between 9 and 15 cubic yards by two independent consulting engineering firms. (Bogart directed project: Langdale Forest Products, Valdosta, Georgia.)

The final residue was analyzed and the individual K-001 constituent levels were below 10 ppm. This treatment was conducted at a rate of 100 cubic yards per week. Additional reactors can be employed to increase the throughput rate.

The LSC process has been used to remediate sites contaminated with oil and grease, such as in oil drilling locations in Louisiana. Three specific sites yielded the following oil/grease data.

Table 2
Oilfield Waste Biodegradation

	Site A	Site B	Site C
Initial	19.5%	28.89%	3.10%
Final	.4%	.97%	.38%
Reduction	98%	97%	88%

Refinery and manufacturing wastes have been degraded to acceptably low levels in Louisiana and Georgia. Compounds degraded in full-scale projects include, in addition to those mentioned earlier, dichloroethane, styrene, vinyl chloride, and other PNA's. See Table 3.

Laboratory simulations of the process have produced remarkable reductions of chlorinated compounds including pesticides, herbicides, and even PCB's. The PCB data is

Table 3
Biodegradation of Petrochemical Contamination

Compound	Initial (mg/l)	Final (mg/l)	Reduction
Styrene	600	.05	100%
Vinyl Chloride	1.4	.035	97.5%
Organics (PNA's)	81,069	19.4	99.8%

included in Table 4. Perchlorethylene, dichloroethane, and trichloroethylene were also degraded. Simple compounds, such as petroleum hydrocarbons and alcohols are literally "bug bait."

There is one problem engendered by the LSC process. That problem relates to large volumes of inert materials, i.e. soils, in the slurry system. Maintaining an optimum, that is aerobic, environment requires that the soils be turned or stirred every 15 minutes if not totally suspended. The size and configuration of the reactor are as critical to this process as is the raw horsepower requirements.

Placing significant amounts of soil into large in-ground reactors precipitates, literally, problems. The mud settles to the bottom and refuses to be cleaned. The bacteria quickly use the available oxygen, and since more oxygen cannot penetrate the mud matrix, the bacterial system becomes anaerobic, and treatment terminates.

A coincidental problem is how to get the soil out of the treatment cell once it has been decontaminted. The answer to both problems is simple: horsepower. The slurry can be suspended by using additional mixers in the reactors. Once treated, this slurry can be pumped out of the reactors and dewatered.

One additional caveat must be posited. Particle size must be carefully monitored. Small stones will be pumped into the cell, settle to the bottom and stay there. Most mixing systems will not suspend the rocks and they will eventually fill the treatment system.

Slurry Reactors

An alternative solution, has been developed which involves controlling reactor size and mechanical action to maintain the slurry. Auxiliary hardware assures appropriate particle size. The initial operations include a power screen operation to remove rocks and debris. This step also pulverizes clods. The fine material is then slurried and passed through a slurry grinder before being introduced into the reactor.

A combination of mixing aerators and slurry circulation techniques maintains the suspension. This affords an opportunity for the bacteria to literally "eat" the contaminant from the soil particles. Decontamination is therefore rapid and complete.

Some initial data are available. Pilot runs were conducted on heavy clay soils in June and July of 1988. The average contamination levels were 15,000 mg/kg of creosote components. Individual samples varied from 10,000 mg/kg to 18,300 mg/kg to 27,800 mg/kg.

Three different cells were operated and sampled. The data are summarized in Table 5. Data are given in mg/kg.

Table 4
Biodegradation of PCB's

Parameter	Initial (mg/kg)	Final (mg/kg)	Reduction	Time
PCB	540	8.2	98.5%	144 hours
Arochlor 1254	6,365	120	98%	10 days
Arochlor 1260	16,975	5	99.9%	6 days
Arochlor 1254 (oil)	20,000	30	99.8%	21 days

Table 5
Biological Decontamination In Slurry Reactor
(Creosote)

Time	Cell 1	Cell 2	Cell 3
Initial	11,414	5,571	9,284
1 week	250	299	30
2 weeks	195	129	4
Reduction	98.3%	98.7%	99.96%

Clays are more difficult to remediate than sandy soils. The contamination is virtually "washed" off of the sand. The clay adsorbs the contaminant and holds it tightly. Thus the requirement for the slurry-state biodegradation as opposed to merely "washing" it.

Groundwater

Biotechnology has been extended to groundwater remediation. A groundwater remediation unit (MiKIE) has been developed and application for patent has been made. The unit uses the basic principles of bioremediation previously outlined. The system employs pump and treat methodology.

Data from two sites are outlined here. Site A was monitored from August 18 through December 14, 1987. Of the 17 effluent analyses, only one had a detectable quantity of pentachlorophenol (PCP). It registered 0.21 mg/l.

Site B was definitely more highly contaminated with one sample of raw water being analyzed as containing 1,730.26 mg/l PCP. Monitoring from April 29 through December 14 yielded nine nondetectable (ND) samples and seven that ranged form 1.09 to 6.77 mg/l PCP.

Progressive samples were taken toward the end of this period and those data are summarized in Table 6. Dates are input sample (I) and output sample (O). Residence time for samples was one day.

Maintenance of a constant feed stream would level out these fluctuations. The data listed in the table are not consecutive. They were interspersed throughout the time period and the feed stream was constantly changing in concentration. The level of detection was .01 mg/l. Therefore, the ND samples contained less than .01 mg/l.

The MiKIE is also being used to treat process waste streams from plants and refineries. The effluent from these systems is being discharged to a local sanitary sewage system.

Table 6
Bioremediation of Groundwater Contamination

Sample	Input (mg/l)	Output (mg/l)	Dates -	In	Out
1.	227.57	ND	Aug.	18	19
2.	48.90	2.09	Oct.	4	5
3.	39.16	2.09	Oct.	27	28
4.	31.49	ND	Nov.	1	2
5.	9.87	.49	Nov.	8	9
6.	12.81	ND	Nov.	15	16
7.	19.77	ND	Nov.	22	23
8.	13.81	ND	Nov.	29	30
9.	9.12	ND	Dec.	13	14

Summary

Bioremediation has been expanded to cover waste sludges, process sludges, contaminated soils, contaminated groundwater, and process water from active plants. Traditional bioremediation techniques have been supplemented and in some cases supplanted by newer technologies.

The handicaps of landfarming have been overcome by the slurry system of treatment. The system is most conveniently and efficiently conducted in specially designed reactors available now. These reactors have been field tested and demonstration data verifies the utility and efficiency of the system.

The cost of bioremediation is site, contaminant, and matrix dependent. General ranges for soil remediation vary from $60 to $80 per cubic yard in the slurry system. Landfarm costs vary from $30 to $40 per cubic yard. Water remediation will average 60¢ per 1000 gallons.

Bioremediation techniques have been applied to nearly every known organic contaminant. Because the contaminant is actually being destroyed, bioremediation is superior to landfilling. In many cases, destruction efficiencies rival those of incineration. Biodegradation is moving toward the designation as treatment of choice.

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